Estimating Agricultural Impacts of Expanded Ethanol Production: Policy Implications for Water Demand and Quality

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by

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Abstract

Feedstock production for large scale development of the U.S. ethanol industry and introduction of cellulose–to-ethanol technology will require extensive changes in land use and impact water demand and quality. This study compares two scenarios: attaining a 60 billion gallon per year target of ethanol by 2030 and a billion gallon per year biodiesel target by 2012 with cellulose-to-ethanol technology introduced in 2012 and also delayed until 2015. Results suggest water demands and quality will vary regionally with cellulosic feedstock production. Policy emphasis on reduced and no-till practices needs to be complementary to increased crop residue use.

Introduction and Objective

The Energy Policy Act of 2005 was a significant landmark in energy policy by requiring that 7.5 billion gallons of fuel come from renewable sources. The Biofuels Security Act of 2007 proposed an even more strenuous requirement of 10 billion gallons of renewable fuels by 2010, 30 billion gallons by 2020, and 60 billion gallons by 2030. Furthermore, biofuels policy has focused on fostering development from feedstock other than corn with a congressional mandate that targets 36 billion gallons per year by 2022 requiring 21 billion gallons from feedstock other than corn. Such a mandate would require large scale cellulosic biomass feedstock production. Studies examining water use and water quality impacts of ethanol feedstock production on a large market scale have not been evaluated. Production of feedstock sufficient to meet a target of 60 billion gallons of ethanol by the year 2030 would likely require considerable changes in agricultural land use. These marked changes in land use will likely result in changes in water demand and water quality.

An important factor determining water use and quality will be the relative reliance on cellulose-to-ethanol feedstock compared with corn grain. Another important factor is the type of tillage production methods used in producing ethanol feedstock. Cellulose-to-ethanol technology will allow a wide variety of feedstock to be used in ethanol production in addition to corn, including wood sources, agricultural residues, such as corn stover, the residue that remains after corn grain is harvested, and dedicated energy crops, such as switchgrass or hybrid poplar. Relative to production of corn grain feedstock, production of cellulose feedstock has two potential avenues of providing environmental benefits. First, cellulosic feedstock use can result in higher yields of ethanol per acre of feedstock production than when corn grain alone is used. The use of corn stover left behind after corn harvest provides an additional ethanol feedstock source for each acre of corn. Furthermore, an acre of switchgrass, a native perennial grass, can produce more gallons of ethanol per acre compared with corn grain. Second, the levels of certain inputs required per ton of cellulosic feedstock produced can be lower than for corn grain. Under environmentally sustainable practices and limiting stover removal to levels that result in tolerable soil losses, the level of inputs per ton of usable feedstock are potentially lower when corn stover is removed as a feedstock along with corn grain. Also, a ton of switchgrass has the potential to use lower inputs than a ton of corn grain production (for example, 40 to 80 pounds of nitrogen per acre compared with 100 pounds per acre on corn). Analysis of large scale development of an ethanol industry, hence, should include water use and quality impacts that would accrue from cellulosic feedstock in addition to corn grain.

While additional environmental benefits could result from cellulose-to ethanol technology, currently, timing of its commercialization is uncertain. The commercialization of this technology is reliant on lowering the cost of enzymes and improvement of the pretreatment (Somerville). In recent years, significant research funds have been granted to deliver advanced cellulosic research on federal, state, university and private institution levels (State Energy Conservation Office). Projects that focus on demonstrating cellulose-to-ethanol technology are also underway. In October 2006, Dupont and Broin announced steps to bring cost effective ethanol derived from corn stover to market. Also in 2006, Mascoma contracted with New York State to build and operate a $20 million cellulosic ethanol demonstration facility. Mascoma and The University of Tennessee are jointly building and plan to operate a five million gallon per year cellulosic biorefinery. The plant is scheduled to be operational in 2010. Because commercialization of cellulose-to-ethanol technology is critical to meeting large scale ethanol production targets and timing is uncertain, analysis of impacts of ethanol industry development should examine how timing of introduction might impact water use and quality.

Physical characteristics of the land, soil, climate, topography, previous land uses, crop location in relation to land uses, and land availability all impact the availability and quality of water resources. Abundant supplies in one area may be of little help to water scarce areas unless infrastructure is available to transport supplies among regions (Frederick). Hence, a comprehensive understanding and quantitative assessment of how large scale biofuel feedstock production will impact regional water demand and quality is needed to develop environmentally and economically sustainable biofuel policies.

The objective of this study is to project the agricultural sector impacts, including land use changes, of expanding ethanol production to 60 billion gallons by the year 2030 and 1 billion gallons of biodiesel by 2012 and to ascertain the impacts on water use and water quality. Results presented include projected ethanol production by feedstock source, changes in land use as a consequence of meeting targeted ethanol production levels, changes in input use (N,P, K fertilizers, herbicides, and insecticides), and changes in water use. The effect of timing of cellulose-to-ethanol introduction is examined. The effect of an increase in reduced and no-till management practices on input use is also evaluated. Implications for policies encouraging feedstock production in a sustainable manner are discussed.

Previous Studies

Modeling a Renewable Energy Sector

A number of studies have addressed various agronomic, economic, and environmental issues associated with use of biomass feedstock for transportation fuels, bioproducts, and power (CEC; De La Torre Ugarte et al.; Delucchi; English, Menard, and De La Torre Ugarte; Evans;

House et al.; Mann and Spath, 2001a and 2001b; McLaughlin et al.; Petrulis, Sommer, and Hines; Shapouri, Duffield, and Wang, 2002 and 2003; Sheehan, et al., 1996 and 2004; Sheehan, Paustian, and Walsh; Sheehan; Urbanchuk; USDA-OCE, 2002a and 2002b; Walsh et al.; Wang, Saricks, and Santini; Whitten; USDOE-EIA).

Economic modeling of bioenergy feedstock has examined carbon displacement potential and has analyzed long-term and intermediate-run outcomes (Adams et al., 1992 and 1999; McCarl; McCarl and Schneider). However, adjustment costs in the short-run resulting from implementation of new technologies and/or policies are not considered by these models (Schneider). Economic impact modeling of use of agricultural feedstock for energy at a market scale has included economic impacts of using alternative feedstock for coal-fired plants in the southeastern United States (English, et al., 2007), economic analysis of producing switchgrass and crop residues for use as a bioenergy feedstock (English, et al., 2004), and the potential regional economic impacts of converting corn stover to ethanol (English, Menard, and De La Torre Ugarte). The agricultural sector and economic impacts of meeting a 60 billion gallon ethanol target by 2030 were projected by De La Torre Ugarte, et al., 2006. However, that analysis stopped short of presenting the water use and water quality effects of meeting the targeted levels of ethanol production.

Environmental Impacts Studies

The net energy value of ethanol has been evaluated by USDA several analyses (Farrell, et. al; Shapouri, Duffield, and Graboski; Shapouri, Duffield, and Wang, 2002 and 2003; Shapouri and McAloon). Sheehan, et al.(2004) performed a lifecycle analysis of collecting corn stover and converting it to ethanol in the state of Iowa with distribution in the Midwest United States for the production and use E85 in a flexible-fuel light-duty vehicle. Their model incorporated results from individual models for soil carbon dynamics, soil erosion, agronomics of stover collection and transport, and bioconversion of stover to ethanol.

Switchgrass has a high root mass and can sequester soil carbon at higher rates than many row crops and fallowed soils. Liebig, *et al.* compared soil carbon stocks in established switchgrass stand with stocks in nearby cultivated cropland. Their results indicated soil carbon benefits not only at near-surface depths, but also at greater depths. These results suggest that switchgrass is effective at deep storage of soil organic carbon. Findings from a study by Ma, Wood and Bransby suggest that after about 10 years of switchgrass culture, compared with fallow soils of similar type, soil organic carbon was 25 to 48 percent higher.

English, et al. (2008) recently evaluated the economic and environmental impacts that would likely occur if 18 billion gallons of ethanol were produced by 2016, from corn alone. The study suggests that many natural resource issues, such as soil quality, water quality as impacted by soil erosion and sedimentation, air quality, and wildlife habitat – will be exceedingly “at risk” given these increased agricultural production pressures. They found that more intensive corn production will occur in the western Corn Belt, higher input use nationally of fertilizer and non fertilizer chemicals, higher erosion and sedimentation rates are likely. This study, also, did not address water quantity implications.

The aforementioned studies provide critical information regarding the net energy balance of ethanol production, input use, and associated environmental impacts such as from greenhouse gases. With the exception of the English, et al. study, the other cited studies examine these balances and impacts on a case level basis or as averages for a particular state. However, they do not evaluate these effects at a market-wide scale. Furthermore, their focus is not on water use and water quality.

Methodology

Two biofuels market scenarios for reaching 60 billion gallons of ethanol by 2030 and 1 billion gallons of biodiesel by 2012 are compared with a baseline scenario (an extension of the 2006 USDA baseline projection through 2030). The first scenario, Cellulosic 2012, projects the impacts of attaining biofuels targets assuming the cellulose-to-ethanol technology will be commercially available by 2012. The second scenario, Cellulosic 2015, assumes that the commercial introduction of cellulose-to-ethanol technology is delayed until 2015. The agricultural sector impacts projected include changes in land use and changes in water use and use of inputs associated with conversion of acreage from prior uses to biofuels feedstock production (N,P,K fertilizers, herbicides, and pesticides).

Conversion technologies selected to meet the biofuels targets include ethanol from shelled corn, ethanol from cellulosic residues (stover, switchgrass, and wheat straw), ethanol from food residues, ethanol from wood residues (forest residues, mill wastes, fuel treatment and forestland thinnings, harvesting of standing stock is not included), biodiesel from soybeans, and biodiesel from yellow grease/tallow. Representative biofuels facility outputs, feedstock use, and associated costs are based upon prior studies (McAloon, et al.; e-mail correspondence from V. Eidman; Aden, et al.; BBI International; English, Jensen, and Menard; Fortenberry).

A listing of key technology and other assumptions is provided in table 1. In addition, adoption of reduced and no-till management practices are assumed to increase. The mixture of practices is assumed to change from conventional tillage 60%, reduced tillage 20%, and no-till 20% to conventional tillage 25%, reduced tillage 20%, and no-till 55% (English et al., 2006).

The targeted biofuels production levels along with data on conversion costs for agricultural and forest feedstock are introduced into POLYSYS to estimate the quantity of biofuels to be produced and the associated price, net farm income, and other agricultural sector impacts. The POLYSYS model (De La Torre Ugarte and Ray) provides annual estimates of changes in land use resulting from the demand created by biofuels production, including changes in economic conditions that affect adjustment costs.

The geographic ranges for switchgrass production are assumed to be limited to areas where it can be produced with high productivity under rain-fed moisture conditions. Geographic regions and yields are based primarily on those contained in the Oak Ridge Energy Crop County Level Database (Graham, Allison, and Becker). Switchgrass yields, by Agricultural Statistical District (ASD), range from an annual rate of 2 to 6.75 dry tons per acre (dt/ac) depending on location. Switchgrass is not available in the first two years of simulation, because switchgrass is not currently produced as a dedicated energy feedstock, and would need to be adopted into production. Expected switchgrass prices are a function of one year lagged market prices. Once planted, the expected yields for switchgrass remain fixed for the life of the production rotation. Also, once acres are planted into switchgrass, they remain in switchgrass through the end of the simulation.

The removal of crop residues such as corn stover and wheat straw raises environmental quality issues such as erosion, carbon levels, tilth, moisture, and long-run productivity. This analysis accounts for quantities of residues that must remain on the field in order to keep erosion at less than or equal to the tolerable soil loss level. The estimated quantities that must remain are determined through the application of the Revised Universal Soil Loss Equation (RUSLE) and consider soil type, slope, crop rotation, type and timing of tillage and other management practices, among other factors (Nelson). The quantities of crop residues that can be removed are the amounts of stover or straw produced minus the highest of the estimated residue quantities needed to control for rain and wind erosion, along with soil carbon. The methodology for estimating quantities that must remain takes into account soil types, slope, crop rotations, type and timing of tillage plus other management practices, including climate zones among other factors (Nelson). In the current analysis, only stover and straw are removed that keep erosion at less than or equal to the tolerable soil loss level. The estimated response curves incorporated into POLYSYS were obtained through the DOE Oak Ridge National Laboratory (ORNL) (Walsh et al.).

The costs of collecting corn stover and wheat straw include baling and staging (loading on bale wagon and moving to field edge) and cost of nutrient replacement. Costs are estimated as a function of the residue that can be removed. The choice of whether residues are harvested from a particular county is determined by calculating the difference between the cost of collecting residues to the edge-of-field and the market revenue generated. If the difference is positive, the residues are harvested from all county corn or wheat acres. Expected prices are projected year residue prices.

The water need for a crop is defined as the amount of water required to meet the water loss through evapotranspiration (ET). The ET is estimated as the water absorbed by a crop from the soil and that is subsequently lost into the air through transpirations and the water lost through evaporation from the soil surface, leaves and stem of a plant (Brouwer and Heibloem). Water needs can be met by precipitation and/or irrigation. The soil acts as a buffer to hold part of the precipitation and release it to plant root systems in times of water deficit. When the stored water is insufficient, for example during long dry periods or in arid climates, water from irrigation needs to be added to satisfy the growing needs of the plant.

The major factors affecting ET are climate, the crop type, and the growth stage. Among the climate related factors the key elements are sunshine, temperature, humidity, and windspeed. These climate factors influence not only the water availability but also the rate at which water is lost into the atmosphere. The crop type influences the water needs mainly through the differences in total leaf surface, and the length of the growing season. The growth stage is a critical influence on the water needs of a plant. During the initial stage of crop development the evaporation will be more important, while during the mid and late season the transpiration becomes more important than the evaporation. An additional factor related to the water use in the late season is whether the crop harvested is a fresh harvest, as in the case of vegetables, or a dry harvest, as in the case of grains. In the first case, the water use during the late season is high, while for the latter case, the water use is low.

The formula use to estimate crop water needs is $ET_{\mathrm{crop}} = ET_{\mathrm{o}} \times K_{\mathrm{c}}$. In the relationship, ET_{o} is the reference crop evapotranspiration, and it represents the influence of climate factors on crop water needs. The reference crop is green grass, and ET_{o} is usually expressed in millimeters per unit of time (mm/day; mm/month; mm/season). The crop factor, K_{c}, represents the influence of crop type on crop water needs. The estimation of both the ET_{o} and K_{c} factors require a significant amount of detailed data. Several methods have been developed for the proper estimation of *ET*. Some of which have been implemented in physical process models such as the Erosion-Productivity Impact Calculator (EPIC) by Williams, Jones, and Dyke or the Agricultural Land Management Alternatives with Numerical Assessment Criteria (ALMANAC) by Kiniry et al. For this research, water need indicative values for different crops were used and set constant across regions and over simulated periods in this research. These values are traditionally used in the absence of ET estimates. The values used are presented in table 2. All values are in the range of the potential evaportranspiration. Therefore, it is not consistent with the 2003 Farm and Ranch Irrigation Survey (Census of Agriculture, 2002), because the survey data provides the estimated quantity of water applied to crops. The water needed for crop growth (ET) is different from actual water applied (some values can be found from the 2003 Farm and Ranch Survey). Water applied to crop land may not exactly equal to ET due to different irrigation technologies, rainfall levels, and previous soil moisture, as well as the deficit irrigation practices that may occur in the case of water shortages or changes in water or energy costs. To accurately estimate water needs, factors such as climate change, irrigation technology adoption, crop species, soil moisture, irrigation schedules, and costs that related to irrigation should all be taking into consideration. Because water applied to the field varies much more than ET and is very difficult to measure, potential water needed was used for this research rather than actual water applied to measure the demand for water in crop production.

Simultaneously with the estimation of the changes in water demand, changes in the impacts on water quality were also estimated. The impact on water quality is measured as changes in the expenditures on chemical herbicides, nitrogen, potassium, and phosphorus. As the estimation of these change in based on differences between the simulated land use and the baseline land use, the changes in the expenditures for the chemicals and fertilizers in the corresponding year of each scenario do reflect changes quantities, as the prices for these inputs are the same for corresponding year of simulation and baseline scenarios. This implies that a simplifying assumption is made: there are no significant price impacts as the use of chemicals and/or fertilizers changes.

Results

Ethanol Production by Feedstock Source

As shown in table 3, attaining the target of 60 million gallons of ethanol by the year 2030 relies on introduction of cellulose-to-ethanol technology. In fact, by the year 2030, it is projected that about 85 percent of ethanol will be derived from cellulose. Over half of the ethanol is projected to come from dedicated energy feedstock sources. If cellulose-to-ethanol technology is delayed (Cellulosic 2015), corn grain ethanol peaks at higher levels than if the technology is introduced earlier (Cellulosic 2012).

Land Use Changes

The land use changes associated with meeting the target of 60 million gallons of ethanol by 2030 are displayed in table 4. Three significant changes in land use occur. First is the emergence of a dedicated energy crop as represented by switchgrass, with over 36 million acres by 2030. The second important change is the transformation of cropland in pasture into production of hay and dedicated energy crops. About 35 million acres of cropland in pasture is projected to be converted to hay production, dedicated energy crops, and other crop production. The third major change is the decrease in soybean acreage. The projected area planted in soybeans declines from 73.3 million acres in 2007 to 67 million acres in 2030. An important effect of delaying cellulose-to-ethanol introduction from 2012 to 2015 is to postpone conversion of pasture acreage to dedicated energy crops and hay. Corn acreage declines are also delayed while soybean acreage declines occur earlier. These effects reflect the expansion of the corn grain ethanol industry until cellulose-to-ethanol introduction. Soybean acreage declines occur earlier with cellulose-to-ethanol technology, partially due to increased availability of distiller's dried grains (DDG's), a byproduct of the corn grain ethanol industry, for use in livestock feed.

The geographic distribution of the production of cellulosic materials can be seen in figure 1. The majority of this cellulosic feedstock production occurs in the eastern half of the United States. Switchgrass is produced primarily in the Southeast, while corn stover is produced in the corn growing areas of the Midwest.

Water Demand Changes

The changes in water demand associated with the changes in land use described above are depicted in figure 2. These values are percentage change away from the USDA extended baseline. With conversion of land out of current uses into dedicated energy crop and hay production, overall water demand is projected to decline by about 0.16-0.18 percent annually by the year 2030 compared with the extended baseline. In addition, the delay of cellulose-to-ethanol technology (Cellulosic 2015) results in higher cumulative water use over the study period than when cellulose-to-ethanol is introduced in 2012 (Cellulosic 2012).

The geographic changes in projected water demand by the year 2030 under the Cellulosic 2012 scenario are depicted in figure 3. This map shows the percent changes in water demand from the extended baseline. The southeastern United States, where much of the dedicated energy crop production would occur, achieves the greatest percentage declines in water use. The dense crosshatch shaded areas represent over a 2 percent decline and as high as over 12 percent decline in water use associated with dedicated energy crop production. In figure 4, a map of national distribution of irrigated land (percentage of irrigated land over harvested land), most of the irrigated land is located in West and some parts of the Southeast. This is consistent with the estimated water use change in figure 3, where water use is not projected to change much in the western part of the U.S., while water use decrease is estimated to result in the southeastern part of the U.S. where the irrigated land density is high.

Input Use Changes

The projected percent changes in N,P,K fertilizers use away from the extended baseline under the assumption of tillage changes are displayed in table 5. By the year 2030, the percent decline in potassium application compared with the baseline is about 14 percent. The percent decline in nitrogen application is just over eight percent and the percent decline in phosphorus application is about four percent. If cellulose-to-ethanol introduction is delayed, wide scale production of switchgrass is also delayed, and the savings in N, P, K applications accruing from 2012 through 2015 are lost. The geographic distribution of changes in nitrogen application in 2030 under the Cellulosic 2012 scenario is shown in figure 5. The largest percentage declines in nitrogen application occur in part of the Southeast and Midwest regions where the decrease can be as much as 21 percent.

The projected percent changes in herbicides and insecticides away from the extended baseline under the assumption of a change in tillage practices are also shown in table 5. By the year 2030, small savings in herbicides use occur, however, the annual decline in insecticide use compared with the baseline is over 11 percent. The geographic distribution of change in herbicide application in 2030 under the Cellulosic 2012 scenario is shown in figure 6. Herbicide use declines where crops such as soybeans are being converted to a dedicated energy crop, while herbicide use increases in areas where pasture is converted to a dedicated energy crop. Large scale of production of new energy crop, such as moving from pasture land to intensive cultivation of native grasses, may impose more pest and weed threads comparing with field that has more diversity in crops or plant species. For example, the herbicide use could increase substantially in the seeding year of switchgrass establishment because the weed may invade the plants as the stands are still thin.

Effects of Changes in Tillage Practices

The results regarding water and input use changes discussed above assume that tillage practices change from conventional tillage 60%, reduced tillage 20%, and no-till 20% to conventional tillage 25%, reduced tillage 20%, and no-till 55%. If no changes in tillage practices are assumed, marked changes in input use occur. First, as shown in table 6, nitrogen and phosphorus expenditures increase away from the extended baseline rather than decreasing. Potassium expenditures decreases away from the baseline, but savings are not as great as when reduced and no-till are adopted at greater rates, as shown in table 6. Second, herbicide use increases away from the baseline by a greater percentage than when reduced and no-till are adopted at greater rates. Furthermore, percentage decreases in insecticide use are lower than when reduced and no-till are adopted at greater rates.

Conclusions

The results from this study suggest that with cellulose-to-ethanol introduction and with increased use of no-till management practices, the production of feedstock for biofuels does not have to place positive pressure on water demands. Furthermore, acceleration of introduction of cellulose-to-ethanol path would ease pressure on water demand originating from the crop production sector.

The effects of holding reduced and no-till adoption at current rates compared with increasing reduced and no-till rates on water demand and input use illustrate the importance of tying economic incentives for biofuels feedstock production to sustainable crops and management practices. The results also suggest that renewed emphasis on reduced and no-till practices needs to be complementary to the increased use of crop residues for energy (and animal feed). Furthermore, the regional differences in land use and environmental conditions reflected in the results from this study denote the need to incorporate specific regional conditions in the design of policy instruments encouraging biofuels feedstock production.

Ethanol industry development impacts on cropping patterns and associated irrigation water demand and runoff of chemicals into water are important, but very complex issues. This research serves as an initial analysis to how ethanol feedstock production may affect demand for and quality of water in the agricultural production sector. Much remains to be explored in relation to how water demand and quality will be affected by expanded ethanol production. A better understanding of the physical, technological, institutional and economic dynamics affecting water demand and water quality will require more detailed regional and community data. For example, actual water applied to cropping field would gave more precise estimation on the water demand change on agricultural production. Additionally, dedicated energy crop production will also affect local feedlot and overall livestock production, which will also serve as an important factor that affect water quality. These livestock sector issues could also be incorporated into the model to support policy decision making related to these issues. In addition to investment adjustment in irrigation and improvement in drainage systems that might affect the future water demand, application of fertilizer and herbicide will also affect groundwater and surface water differently. Future research should focus on the water management difference of conventional crops and energy dedicated crops in field production with regard to technology development and adjustment as well as the location and water resources of biofuel feedstock production and ethanol plants that may be affect the community water availability and accessibility.

Another limitation of this research is the long run food price adjustment. However, cellulosic ethanol development may not affect food price dramatically because many lands that would be converted to energy dedicated crops production are pasture land or marginal land. It is true that rising food price will promote the food crop production in a more intensive scale and may result in a higher irrigation rate.

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Table 1. Key study assumptions

Conversion coefficients for cellulose (stover, straw, and dedicated energy corps) to ethanol	Increased linearly from 2015 to 2030
Conversion coefficients for corn grain ethanol and biodiesel	Increase through 2019 and remain constant after 2019
Yield gains in switchgrass	Year 2021 and beyond 1.5% (North East, Lakes States, North Plains), 5% (Appalachia, Southeast, Southern Plains), and 3% (Corn Belt)
Yield gains for traditional crops	Corn (1.13%), sorghum (0.76%), oats (0.61%), barley (0.88%), wheat (0.88%), soybeans (0.93%), cotton (0.43%), and rice (0.79%)
Land base	Include 307 million acres of cropland in major crops plus hay and 56.2 million acres of cropland in pasture
Maximum percents of Distiller's Dry Grains (DDG's) useable in feed rations	Limited to 30 percent for beef and 10 percent for dairy, hogs, and broilers
Regional intensification of livestock constant.	Held constant so livestock shifts not incorporated

Table 2. Indicatives mean values of crop water need[a]

Crop Name	Mean Crop Water Need
	Inches/Total Growing Period
Corn	26
Sorghum	22
Oats	22
Barley	22
Wheat	22
Soybeans	23
Cotton	39
Rice	23
Switchgrass	25
Hay/alfalfa	25
Pasture	25

[a] All values except that for switchgrass, hay and pasture are taken form Brouwer and Heibloem (1986). The hay/alfalfa and pasture values are from NRCS Plants Database. The switchgrass value is taken from Stroup (2003) and Smith (2007).

Table 3. Ethanol production from feedstocks under two cellulose-to-ethanol introduction scenarios [a]

Feedstock	2010	2015	2020	2025	2030	Percent of Ethanol Produced in 2030
			Billion Gallons			
Corn Grain:						
Cellulosic 2012	10.0	15.9	10.8	9.2	8.9	14.7%
Cellulosic 2015	10.0	9.6	9.2	8.8	8.8	14.5%
Wood Residues:						
Cellulosic 2012	0.0	1.6	3.8	4.4	5.5	9.1%
Cellulosic 2015	0.0	4.2	3.8	4.5	5.2	8.5%
Wheat Straw:						
Cellulosic 2012	0.0	0.0	0.5	1.0	1.8	2.9%
Cellulosic 2015	0.0	0.6	0.4	1.2	1.7	2.8%
Corn Stover:						
Cellulosic 2012	0.0	0.0	0.0	5.7	12.1	20.0%
Cellulosic 2015	0.0	1.8	0.0	8.4	10.8	17.8%
Dedicated Energy Crop:						
Cellulosic 2012	0.0	0.0	14.4	24.8	32.1	53.2%
Cellulosic 2015	0.0	3.6	16.7	22.4	34.0	56.3%
Total Production:						
Cellulosic 2012	10.0	17.6	29.4	45.1	60.4	
Cellulosic 2015	10.0	19.8	30.0	45.2	60.4	

[a] The Cellulosic 2012 scenario introduces cellulose-to-ethanol technology in 2012, while the Cellulosic 2015 scenario delays the introduction to 2015.

Table 4. Land use under two cellulose-to-ethanol introduction scenarios [a]

Crop and Scenario	2007	2010	2015	2020	2025	2030	Change in Acres 2007-2030
				Million Acres			
Corn:							
Cellulosic 2012	81.2	83.7	83.6	82.4	78.8	76.0	-5.2
Cellulosic 2015	81.2	83.7	87.1	81.2	79.4	75.5	-5.7
Extended Baseline	81.0	84.5	84.5	83.5	82.5	81.7	0.7
Soybeans:							
Cellulosic 2012	73.3	72.9	72.5	69.7	67.9	67.0	-6.3
Cellulosic 2015	73.3	72.9	69.1	70.0	67.9	67.0	-6.3
Extended Baseline	73.3	71.5	70.5	69.2	68.0	66.6	-6.7
Wheat:							
Cellulosic 2012	57.9	57.6	57.9	57.1	56.4	56.6	-1.3
Cellulosic 2015	57.9	57.6	58.1	57.6	56.1	58.6	0.7
Extended Baseline	58.0	57.5	58.5	59.2	59.4	59.7	1.7
Other Crops:							
Cellulosic 2012	32.5	32.1	30.4	29.6	29.2	27.9	-4.6
Cellulosic 2015	32.5	32.1	32.3	30.0	29.2	27.8	-4.7
Extended Baseline	32.5	32.1	32.0	32.1	32.1	32.1	-0.4
Hay:							
Cellulosic 2012	62.3	62.3	66.6	70.0	72.6	73.8	11.5
Cellulosic 2015	62.3	62.0	61.1	66.8	70.9	73.0	10.7
Extended Baseline	62.4	62.6	62.2	62.2	62.2	62.2	-0.2
Pasture:							
Cellulosic 2012	56.5	56.5	43.2	30.5	24.3	20.8	-35.7
Cellulosic 2015	56.6	56.6	56.6	35.4	26.8	21.6	-35.0
Extended Baseline	56.5	56.5	56.5	56.5	56.5	56.5	0
Dedicated Energy Crop:							
Cellulosic 2012	0.0	0.0	9.86	23.3	31.7	36.8	36.8
Cellulosic 2015	0.0	0.0	0.0	21.8	30.6	37.4	37.4

[a] The Cellulosic 2012 scenario introduces cellulose-to-ethanol technology in 2012, while the Cellulosic 2015 scenario delays the introduction to 2015.

Table 5. Changes in input use under two cellulose-to-ethanol scenarios [a]

	Year				
Input and Scenario	2010	2015	2020	2025	2030
	Percent Change Away from the Baseline				
Fertilizers:					
Potassium					
Cellulosic 2012	-0.22	-5.56	-10.67	-12.80	-14.30
Cellulosic 2015	-0.22	-0.71	-9.93	-12.20	-14.33
Nitrogen					
Cellulosic 2012	-0.73	-3.76	-6.17	-7.51	-8.55
Cellulosic 2015	-0.73	0.49	-6.01	-7.05	-8.60
Phosphorus					
Cellulosic 2012	-0.32	-2.32	-3.57	-3.75	-3.62
Cellulosic 2015	-0.32	-0.36	-3.22	-3.53	-3.59
Other Agrichemicals:					
Herbicides					
Cellulosic 2012	0.25	0.82	1.23	0.52	-0.11
Cellulosic 2015	0.25	0.87	0.59	0.45	-0.33
Insecticides					
Cellulosic 2012	-0.39	-4.29	-6.76	-9.34	-11.58
Cellulosic 2015	-0.39	0.46	-6.90	-9.19	-11.97

[a] The Cellulosic 2012 scenario introduces cellulose-to-ethanol technology in 2012, while the Cellulosic 2015 scenario delays the introduction to 2015.

Table 6. Changes in input use under two cellulose-to-ethanol scenarios with no changes in tillage practices [a]

	Year				
Input and Scenario	2010	2015	2020	2025	2030
	Percent Change Away from the Baseline				
Fertilizers:					
Potassium	-0.22	-4.27	-5.58	-6.59	-6.20
Cellulosic 2012	-0.22	-0.71	-5.48	-5.83	-6.68
Cellulosic 2015					
Nitrogen	-0.73	-1.25	3.37	3.39	5.56
Cellulosic 2012	-0.73	0.49	2.61	4.56	5.02
Cellulosic 2015					
Phosphorus	-0.32	0.07	5.54	7.01	10.44
Cellulosic 2012	-0.32	-0.36	4.87	7.76	9.96
Cellulosic 2015	-0.22	-4.27	-5.58	-6.59	-6.20
Other Agrichemicals:					
Herbicides					
Cellulosic 2012	0.25	6.94	2.56	9.00	4.04
Cellulosic 2015	0.25	0.87	3.43	5.19	6.94
Insecticides					
Cellulosic 2012	-0.39	-4.29	-6.76	-9.34	-11.58
Cellulosic 2015	-0.39	0.46	-6.90	-9.19	-11.97

[a] The Cellulosic 2012 scenario introduces cellulose-to-ethanol technology in 2012, while the Cellulosic 2015 scenario delays the introduction to 2015.

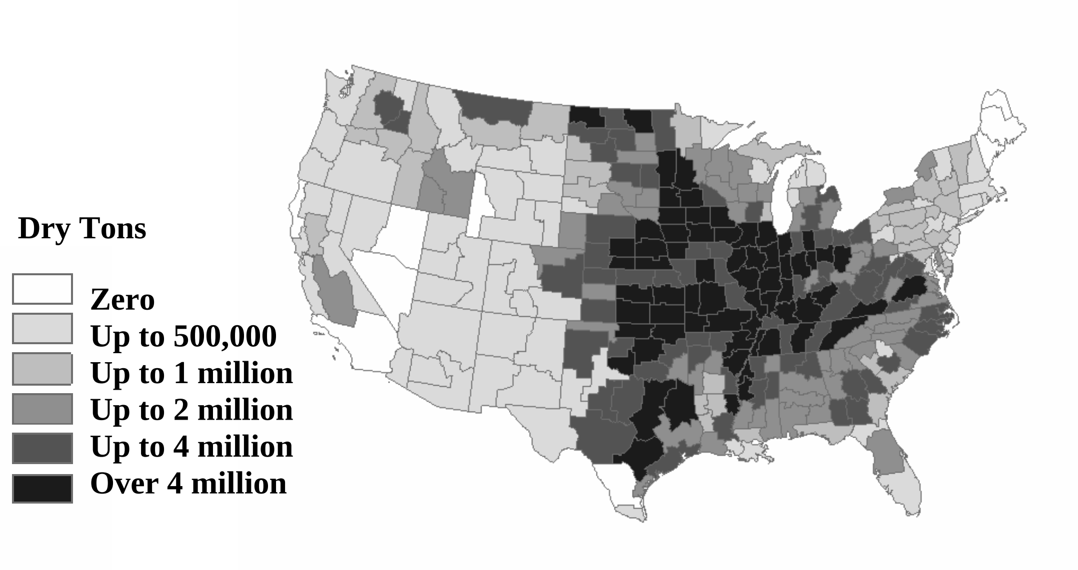

Figure 1. Geographic distribution of the production of cellulosic feedstock in 2030 under the Cellulosic 2012 scenario

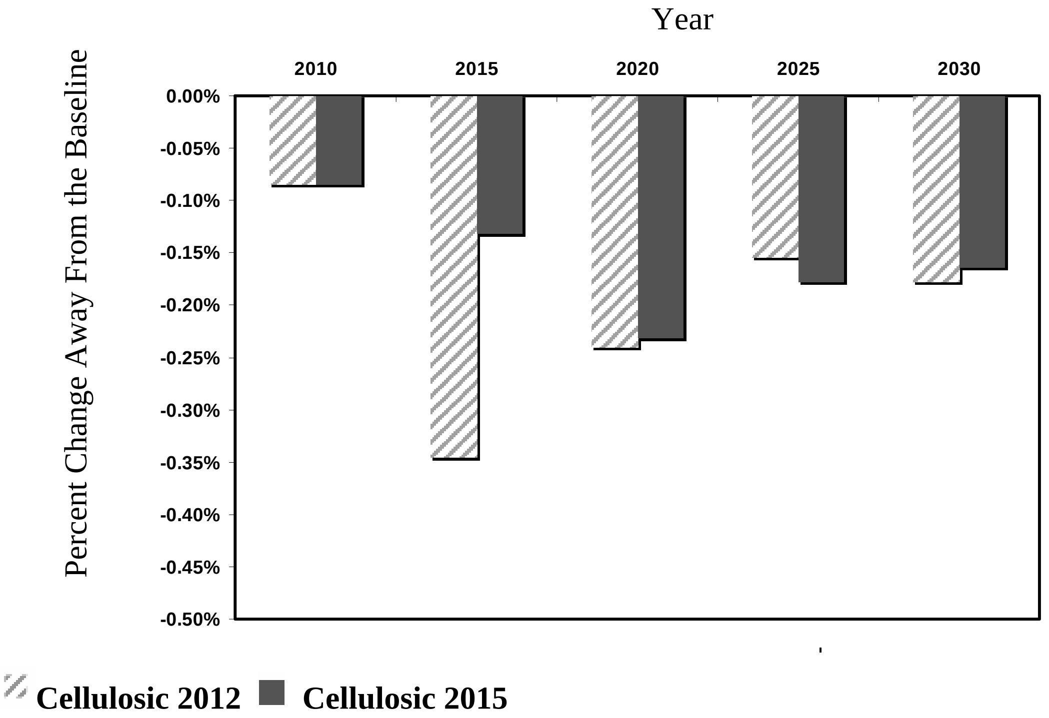

Figure 2. Changes in water use under two cellulose-to-ethanol introduction scenarios [a]

[a] The Cellulosic 2012 scenario introduces cellulose-to-ethanol technology in 2012, while the Cellulosic 2015 scenario delays the introduction to 2015.

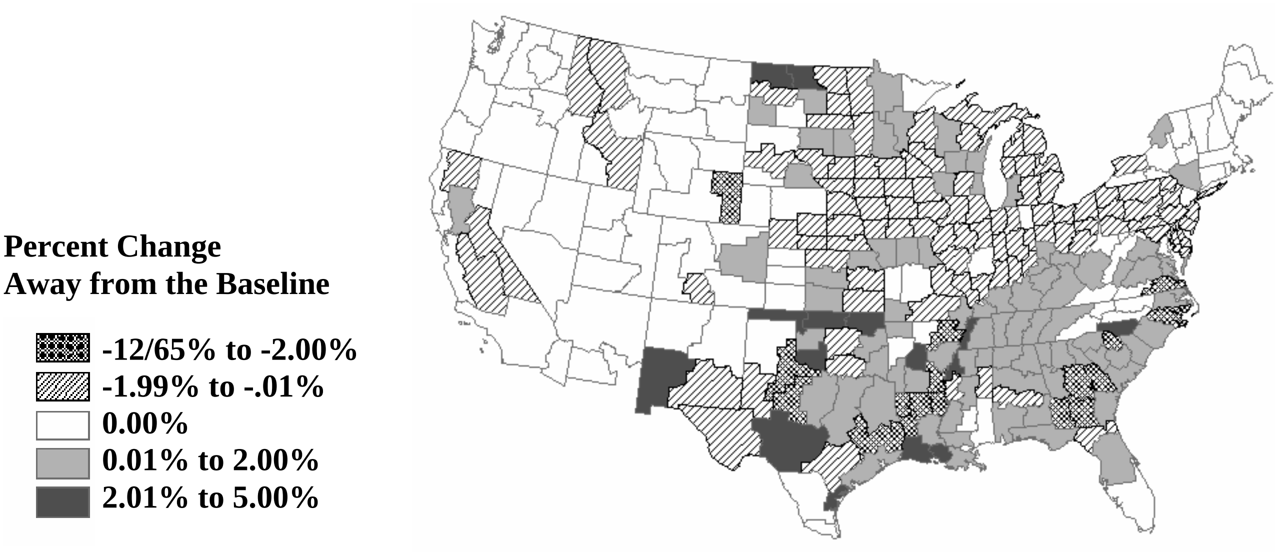

Figure 3. Geographic changes in water use in 2030 under the Cellullosic 2012 scenario

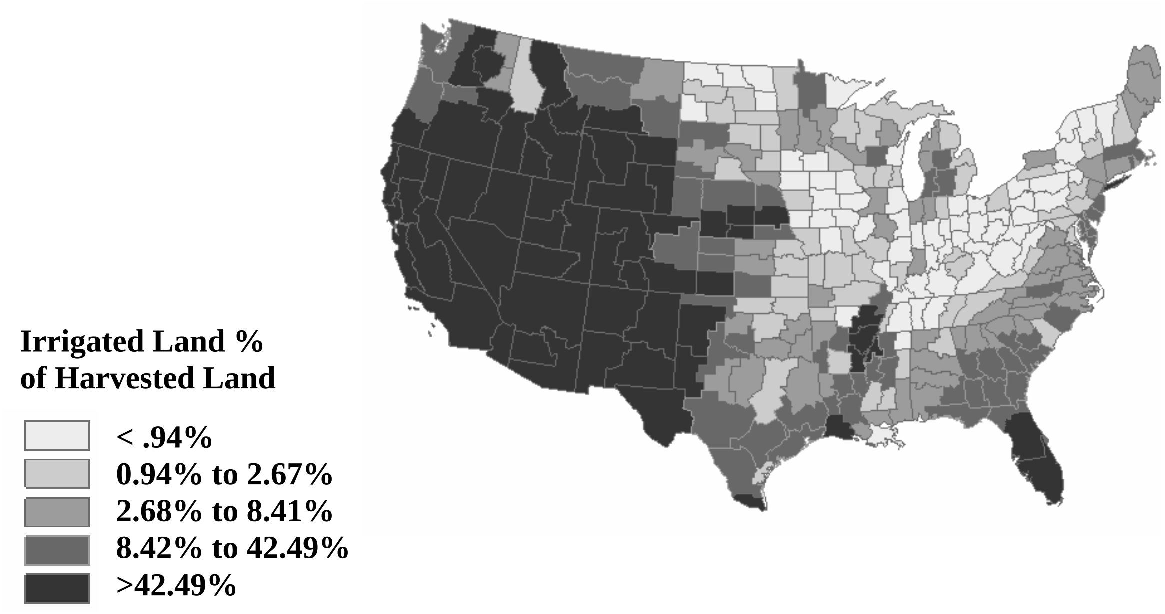

Figure 4: Irrigated land as a percentage of harvested land, 2002[a]

[a] Source: USDA/NASS Census of Agriculture 2002.

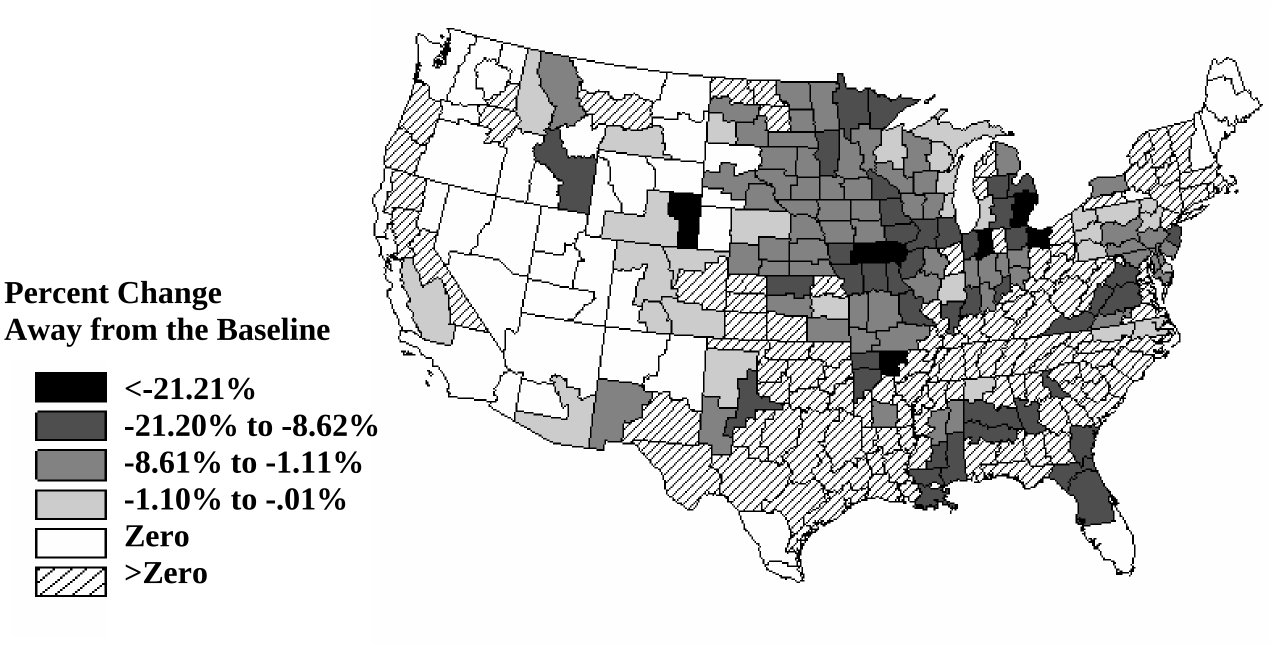

Figure 5. Geographic changes in nitrogen application in 2030 under the Cellulosic 2012 scenario

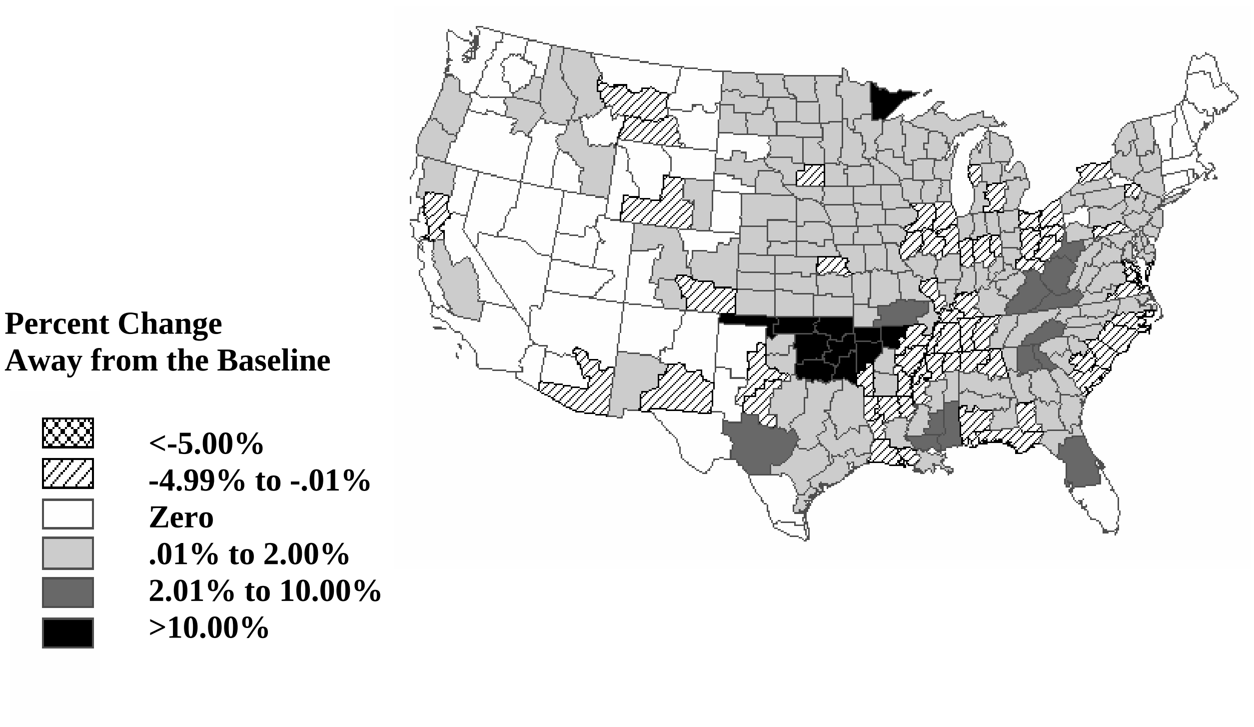

Figure 6. Geographic changes in herbicide application in 2030 under the Cellulosic 2012 scenario