Simulated impact of the renewable fuels standard on US Conservation Reserve Program enrollment and conversion

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Abstract

A socioeconomic model is used to estimate the land-use implications on the U.S. Conservation Reserve Program from potential increases in second-generation biofuel production. A baseline scenario with no second-generation biofuel production is compared to a scenario where the Renewable Fuels Standard (RFS2) volumes are met by 2022. We allow for the possibility of converting expiring CRP lands to alternative uses such as conventional crops, dedicated second-generation biofuel crops, or harvesting existing CRP grasses for biomass. Results indicate that RFS2 volumes (RFS2-v) can be met primarily with crop residues (78% of feedstock demand) and woody residues (19% of feedstock demand) compared with dedicated biomass (3% of feedstock demand), with only minimal conversion of cropland (0.27 million hectares, <1% of total cropland), pastureland (0.28 million hectares of pastureland, <1% of total pastureland), and CRP lands (0.29 million hectares of CRP lands, 3% of existing CRP lands) to biomass production. Meeting RFS2 volumes would reduce CRP re-enrollment by 0.19 million hectares, or 4%, below the baseline scenario where RFS2 is not met. Yet under RFS2-v scenario, expiring CRP lands are more likely to be converted to or maintain perennial cover, with 1.78 million hectares of CRP lands converting to hay production, and 0.29 million hectares being harvested for existing grasses. A small amount of CRP is harvested for existing biomass, but no conversion of CRP to dedicated biomass crops, such as switchgrass, are projected to occur. Although less land is enrolled in CRP under RFS2-v scenario, total land in perennial cover increases by 0.15 million hectares, or 2%, under RFS2-v. Sensitivity to yield, payment and residue retention assumptions are evaluated.

Keywords: Conservation Reserve Program, Energy Independence and Security Act, land-use change, Renewable Fuel Standard, second-generation biofuels

Introduction

Changes in agricultural policy lowering the cap on Conservation Reserve Program (CRP) lands, together with a rapid increase in commodity prices since 2007, have likely spurred some Conservation Reserve Program (CRP) contract holders to not re-enroll and convert CRP lands to other uses (United States Congress, 2008; Wright & Wimberly, 2013). Over 3.64 million hectares of CRP lands have transitioned to other uses since 2007, declining from 14.89 million hectares nationally to 10.24 million hectares by the end of 2013 (United States Department of Agriculture, 2014a). Total over the same time period, 9.31 million hectares of CRP and non-CRP grasslands, shrublands, and wetlands have been tilled and converted to annual crop production (Faber et al., 2012). Such large conversions of perennial cover can have negative environmental implications, including reductions in soil carbon, loss of wildlife habitat, and increased pollutant discharge to streams (Fargione et al., 2010). Several analyses have indicated that government biofuel mandates were one of several key drivers (along with increased food demand, falling dollar value, and oil price increases) in commodity prices surges and resulting land-use changes (Congressional Budget Office, 2009; Tyner, 2010; Hochman et al., 2012; De Gorter et al., 2013).

The Energy Independence and Security Act of 2007 (EISA) established a new renewable fuels standard (RFS2) requiring the production of 36 billion gallons of renewable fuels by 2022. RFS2 requires 21 billion...
gallons of the total mandate to be from advanced biofuels, with a net greenhouse gas (GHG) offset of 50% or more (United States Congress, 2007). Advanced biofuels can come from a variety of sources (e.g., cellulose, algae, etc.), but the main source anticipated to fulfill 16 of the 21 billion gallon target is from lignocellulosic biofuel (United States Environmental Protection Agency, 2010a). Lignocellulosic feedstocks are woody or herbaceous, nonfood feedstocks, which often have better net energy returns (assuming little indirect land-use change) than first-generation corn-grain ethanol (Schmer et al., 2008). Additionally, the perennial root systems of most lignocellulosic crops reduce erosion, stream sedimentation, and nutrient loss by holding soil in place (Gelfand et al., 2013). Yet technical and economic hurdles have stunted development of second-generation biofuels, forcing the Environmental Protection Agency (EPA) to reduce the mandated quantities set out in the 2007 expansion of the Renewable Fuels Standard for the fourth year in a row (United States Environmental Protection Agency, 2010a). Only 422 000 gallons of lignocellulosic fuels had been sold in 2013 (United States Environmental Protection Agency, 2014), far below the original mandate timeline level of 1 billion gallons, and still significantly below the reduced mandate level.

If technical and economic hurdles can be overcome, second-generation biofuels could significantly change current US agricultural land use. In a previous study, we estimated that fulfilling RFS2 mandate would convert 8.10 million hectares of pastureland and 7.28 million hectares of cropland to perennial feedstocks by 2025 (English et al., 2010). Yet our previous study did not include the potential conversion of CRP lands which represent a large land base of potential biomass expansion (Dale et al., 2010, 2011). Other studies such as the Department of Energy’s Billion-Ton Study (United States Department of Energy, 2005) and subsequent update (United States Department of Energy, 2011) assume no land-use conversion of conservation lands, which are very useful for establishing potential benchmarks, but these assumptions may be at odds to the policy-decline in CRP enrollment and observed land cover changes (Wright & Wimberly, 2013).

As the second-generation biofuel industry emerges, there are questions about its impact upon CRP lands that currently deliver several ecosystem services. How much CRP land will not re-enroll? Which regions will be most affected? If CRP land converts, will it be to dedicated perennial feedstocks (in which case many services may be preserved) or to annual crops (in which case many services will not be preserved)? In this study, we evaluate the land-use implications of an expanding biofuel industry upon existing CRP contract lands as they expire over the next 15 years.

Materials and methods

To estimate the impact of the RFS2 upon CRP lands, we use a socioeconomic model to simulate land-use changes from 2014 through 2028 from all US agricultural lands, including CRP lands. Given the annual volumetric demand levels of ethanol established by the RFS2 through 2022 (and using 2022 volumes through 2028), the model endogenously determines the feedstock prices needed to produce enough feedstock to meet the mandate, the resulting ripple effect on the prices of other commodities, and the land-use changes the new prices bring about.

The analytical tool used to conduct this analysis is a modified version of the University of Tennessee’s Policy Analysis System model (POLYSYS), which is a partial equilibrium displacement model that iterates annually and simulates results until the year 2028 (De La Torre Ugarte et al., 1998; Ray et al., 1998a; De La Torre Ugarte & Ray, 2000). POLYSYS has been used extensively by USDA and other researchers for estimating the potential supply of second-generation feedstocks at given feedstock prices, and impacts upon supplies of other crops, market prices, and government payments (United States Department of Energy, 2005, 2011; De La Torre Ugarte et al., 2006, 2009; English et al., 2006; Walsh et al., 2007; Hellwinckel et al., 2010). None of these previous studies included CRP lands as a potential source of biomass. We describe briefly here the POLYSYS model and the additional Conservation Reserve Program linear programming module.

Agro-economic modeling

The POLYSYS modeling framework can be conceptualized as a variant of an equilibrium displacement model (EDM), which has been previously developed to simulate changes in economic policy, agricultural management, and natural resource conditions, and to estimate the resulting impacts from these changes on the US agricultural sector (Ray et al., 1998b; Lin et al., 2000; De La Torre Ugarte & Ray, 2000; ). At its core, POLYSYS is structured as a system of interdependent modules simulating (a) crop supply for the continental USA, which is disaggregated into 3110 production regions; (b) national crop demands and prices; (c) national livestock supply and demand; and (d) agricultural income. Variables that drive the modules include planted and harvested area, production inputs, yields, exports, costs of production, demand by use, commodity price, government program outlays, and net realized income. Crops currently considered in POLYSYS include corn, grain sorghum, oats, barley, wheat, soybeans, cotton, rice, and hay, which together comprise approximately 90% of the US agricultural land acreage. Second-generation biofuel crops are also considered including crop residues, woody residues, switchgrass, poplars, willows, and sweet sorghum. This analysis also adds harvesting of established native and non-native grasses from CRP lands to the model.

POLYSYS anchors its analyses to US Department of Agriculture (USDA) published baseline of yield, acreage, and price projections for the agriculture sector, which are endogenously expanded from the USDA 10-year baseline projection period through 2028 for this analysis (United States Department of Agriculture 2015). Changes in agricultural land use, based on
cropland allocation decisions made by individual farmers, are primarily driven by the expected productivity of land, the cost of crop production, the expected economic return on the crop, and market conditions. The POLYSYS model is well-suited to this particular analysis because of the high geographic resolution of land-use decision making (county level), and the ability of market clearing equilibriums to be determined annually. These model qualities enable analysis of land impacts at geographic and temporal units in line with the reporting level of CRP data.

Budgets for all crops are developed using the APAC Budgeting System (ABS) (Slinsky & Tiller, 1999). ABS generates detailed field operation schedules and associates per-hectare crop production costs for all production systems considered. The method used is consistent with those used by USDA and recommended by the American Agricultural Economics Association (American Agricultural Economics Association 2000). The budgets were calculated using 2013 input costs and energy prices, and are used in the model as ‘enterprise’ budgets, where each crop’s costs and returns are used individually and not in rotations.

To simulate the impact of specific biofuel mandates such as RFS2, the annual biofuel demand levels (set by the RFS2) are exogenously fed into the model, POLYSYS incrementally increases feedstock prices, and lowest cost feedstocks are brought into production first until sufficient feedstocks are supplied to meet each year’s mandated level of ethanol. This results in land-use changes from the ‘business as usual’ baseline case that represents the potential impact of the biofuel policy upon land use. Our baseline case is a temporally extended version of USDA Economic Research Service 2015 baseline projections for the crop and livestock sectors (United States Department of Agriculture, 2015). All prices are reported here in nominal terms of the year indicated.

The amount of crop residue produced depends on the crop yield and the harvest index or ratio of residue to grain (1 to 1 for corn) (United States Department of Energy, 2011). The amount that can be sustainably removed is governed by the retention coefficients, which are estimated from application of the revised Universal Soil Loss Equation 2 (RUSLE2) and the Wind Erosion Prediction System (WEPS) models incorporating the soil conditioning index and tillage (Muth et al., 2011). The retention coefficients for corn range from 0.13 to 11.67 Mg ha$^{-1}$ with an average of 3.86 Mg ha$^{-1}$. The amount that can be economically removed depends on the offered feedstock prices and harvesting costs. The percentages of total available residues harvested range from 16% to 95% (average of 56%) depending on the unique crop and county-specific retention coefficients.

Woody residues from private forestlands and mill wastes are also available to the model to satisfy cellulosic feedstock requirements. Forestlands are not endogenously modeled within POLYSYS; rather, exogenous supply curves are entered into the model to pull available supplies at modeled feedstock prices. We use the supply curves explained in the Department of Energy’s Billion-Ton Update (United States Department of Energy, 2011). Supply curves exclude all federal- and state-owned lands and only include biomass supplies from private-land thinnings, logging wastes, and mill wastes, and add up to about 41 million dry Mg at prices below $91 dry Mg$^{-1}$.

**Conservation Reserve Program module**

For this analysis, we constructed an additional linear programming module for existing CRP lands. The model solves in each of 3110 counties individually from 2014 through 2028. Expiring CRP lands can either (1) re-enroll in CRP, (2) convert to traditional annual crops, (3) convert to dedicated energy crops which include switchgrass, poplars, or willows, (3) convert to pasture management, or (4) harvest established grasses for biofuel demand (Tilman et al., 2006). Expiring contracts total 10.24 million hectares and include both general and continuous sign-up, as reported by the Farm Service Agency, scheduled to expire from 2014 through 2028 (United States Department of Agriculture, 2014b) (Fig. 1). The re-enrollment rate has been 56% for expiring CRP acreage between 2007 and 2013. In this study, we only evaluate the potential land-use decisions for existing expiring CRP acreage, but new lands that were not previously in CRP come into CRP contracts every year. Landowner rationales for entering into CRP for the first time are varied and difficult to model. Since 2007, new lands brought into CRP comprise a median of 2% of total CRP acreage. Therefore, over the time period of this analysis, it can be assumed that an additional 1.84 million hectares of new lands not previously in CRP will be added to the CRP re-enrollment totals estimated in our analysis.

For re-enrolling lands, net returns equal the inflated value of current county average CRP rental rates. We use the reported Farm Service Agency average county CRP rental rates in 2013 and inflate them annually at the national 5-year historical average rate of change in nominal CRP rental rates, which is estimated at 2.2% (United States Department of Agriculture, 2014a). Net returns on pasture management equal the county average pasture rental rates. Net returns of conventional crop production and switchgrass equal gross returns minus production costs. Production costs of conventional crops and switchgrass equal the county-level POLYSYS ABS budget estimates.

![Fig. 1 Location of 10.24 million hectares of CRP lands scheduled to expire by 2028.](image)
plus a one-time land conversion cost. The land conversion cost is estimated to be 300US$ per hectare based on updated ABS-consistent costs following reduced tillage operations listed by the University of Nebraska recommendations on conversion of CRP land to cropland (Lyon & Holman, 2009). Expected commodity prices are naïve and equal the model-determined previous year’s equilibrium price between supply and demand. Gross returns of each crop alternative are equal to the expected commodity price times a land-productivity adjusted county-level yield estimate (explained below). If harvesting established grasses, no fertilization is assumed and total costs equal the harvesting costs. Net present value of each alternative option is estimated over 20 years. When county CRP lands expire, net present values of all alternatives are compared and the highest net present value determines land use.

Estimated biomass yields from harvesting established CRP grasses are the higher of either Oak Ridge National Laboratory’s PRISM model estimates for grassland yield or NASS pasture yield averages (2009–2011). ORNL used the empirical results of CRP yield field trials to calibrate the PRISM model which estimated grassland yields for all counties (Lee et al., 2013). County-level switchgrass yields were also derived using the PRISM model (Jager et al., 2010). Our estimates of established CRP grass yield levels average only 1.5 tons ac⁻¹, whereas our estimates of switchgrass yields average 6.0 ton ac⁻¹. A list of assumptions of alternative management options available to existing CRP lands is provided in the Appendix (Table A1).

Determined conventional crop yields on returning CRP lands

A crucial factor in determining future land use of current CRP is the potential yield of alternatives on returning CRP lands. Many previous studies evaluating conversion of CRP to cropland assume a fixed percentage decline from county-level average crop yields on CRP lands. For example, Walsh et al. (2003) applied a 15% decline in yield on returning CRP acreage, De La Torre Ugarte & Hellwinckel (2006) applied a 25% decline, and Li (2011) applied a 40% decline. Secchi et al. (2009) used the corn suitability index in Iowa to adjust yields at the parcel level. Similarly, Hellerstein & Malcolm (2011) adjusted yields at the parcel level by figuring the ratio of individual parcel soil rental rate to the county average soil rental rate.

In this study, we estimate county and crop-specific yield reductions on potentially converting CRP lands using soil quality and land-use data layers. Our goal was to determine how much the productivity on CRP lands deviates from county average productivity for each crop. The main data tool allowing us to differentiate crop yield on CRP from existing crop yields is the recently available national coverage of the Natural Resources Conservation Service’s National Commodity Crop Productivity Index (NCCPI) (United States Department of Agriculture, 2008). In evaluating future land enrollment in CRP, the Farm Service Agency will be using the NCCPI index to determine the productivity of the soil as one of the determinants in setting CRP soil rental rates (Harden, 2012).

In our analysis, average productivity on historic conventional cropland is determined from reported National Agricultural

| Management Option | Assumptions                                      |
|-------------------|--------------------------------------------------|
| Re-enrollment     | 2013 average county-level rental rates + historic average increase in rental rate (2.2% yr⁻¹) |
| Pasture           | Net return = pasture rental rate inflated annually |
| Crops             | NCCPI value to crop yield                        |
| Harvest CRP grasses| Costs of production = ABS estimated crop budgets |
| Harvest Willows   | Net return = (price*yield) – harvest costs – land conversion cost |
| Harvest Poplars   | Average mature yield = 11.1 dry tons ha⁻¹ (harvest every 8 years) |
| Harvest Poplars   | Average operation costs = $182.8 ha⁻¹ yr⁻¹     |
| Harvest Poplars   | Average harvest costs = $19 dry ton⁻¹           |
| Harvest Poplars   | Conversion cost = $297 ha⁻¹ onetime cost        |
| Harvest Poplars   | Net return = (price*yield) – harvest costs – land conversion cost |
| Harvest Poplars   | Average mature yield = 13.1 dry tons ha⁻¹ (harvest every 4 years) |
| Harvest Poplars   | Average operation costs = $195 ha⁻¹ yr⁻¹       |
| Harvest Poplars   | Average harvest costs = $19 dry ton⁻¹           |
| Harvest Poplars   | Conversion cost = $297 ha⁻¹ onetime cost        |

Statistics Service (NASS) county-level yield averages. We use the 3-year average NASS yields from 2009 and 2011 for existing cropland yields in the model, but we adjust the productivity of CRP lands vs. existing croplands by overlaying several data layers.

The NRCS gridded Soil Survey Geographic (gSSURGO) Database includes national coverage of the NCCPI which assigns a productivity value between 0 (lowest potential productivity score) and 1 (highest potential productivity score) depending on relative scoring of subrules in a map unit’s soil, chemical, water, physical, climate and landscape characteristics (Soil Survey Staff, 2013). The NCCPI variables are an interpretation of the National Soil Information System (NSIS) data.

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NSIS has national coverage and a consistent methodology of rating across geographic boundaries. We use the NCCPI database variable ‘NCCPI_overall’, which is the highest value among corn and soybeans, small grains, or cotton (weighted average) for major earthy components. Earthy components are those soil series or higher level taxa components that can support crop growth (Soil Survey Staff, 2013). Resolution of NCCPI is at the SSURGO ‘map unit’ polygon level.

Beginning with the NCCPI layer, we then overlay FSA 2012 CRP field-level boundaries to determine the average NCCPI value of CRP lands in each county (Fig. 2) (Farm Service Agency, 2013). We also overlay USDA Cropland Data Layer (United States Department of Agriculture, 2013) to determine the county-level average NCCPI value of each crop. NCCPI value of each crop is plotted with each county’s known average NASS crop yield. Ordinary least squares method was used to linearly estimate the crop-specific relationship between NCCPI value and reported average yields. Figure 3 shows the scatter plot with one estimated curve. The curves allow us to estimate yield associated with a given NCCPI value by crop using the slope (b1 coefficient) to adjust the county NASS mean yield by NCCPI value (Fig. 3). Table 1 lists the estimated relationships between NCCPI value and yield by crop. By applying these yield changes to the weighted NCCPI values for existing CRP lands nationally, we can determine yield decline of conventional crops if planted on existing CRP lands. Nationally, average crop yield declines range between 16% (soybeans) and 33% (cotton).

Scenarios examined

We compare two scenarios to estimate the impact of RFS2 on CRP land use;

1 Baseline – simulate through 2028 with no second-generation ethanol expansion.

2 RFS2-volumes (RFS2-v) – simulate through 2028 with second-generation ethanol reaching RFS2 volumetric goals by 2022.

The difference between baseline land use and RFS2-v land use will approximate the net impact of second-generation biofuels on land acreage in the USA, including CRP. To meet RFS2 mandates, cellulosic feedstocks are considered in the

Table 1 Estimated b1 value of the estimated linear equation, adjusted R-squared, and the estimated national average percentage yield decline of conventional crops if planted on existing CRP lands

| Crop         | Yield unit | Estimated b1 value† | Adjusted R-squared | Estimated average yield decline on existing CRP lands, % |
|--------------|------------|---------------------|---------------------|--------------------------------------------------------|
| Corn         | Mg ha⁻¹    | 7.73****            | 0.4332              | -22.3                                                  |
| Sorghum      | Mg ha⁻¹    | 5.72****            | 0.4259              | -23.8                                                  |
| Oats         | Mg ha⁻¹    | 2.85****            | 0.2577              | -28.7                                                  |
| Barley       | Mg ha⁻¹    | 3.81****            | 0.4495              | -17.3                                                  |
| Wheat        | Mg ha⁻¹    | 3.22****            | 0.2844              | -31.4                                                  |
| Soybeans     | Mg ha⁻¹    | 1.62****            | 0.1648              | -16.6                                                  |
| Cotton       | Mg ha⁻¹    | 0.77****            | 0.3327              | -32.8                                                  |

****Significant at P < 0.0001.
†Represents the change in yield for a one unit change in NCCPI value from the linear regression equation (crop yield = b0 + b1*NCCPI value).

Fig. 3 Scatter plot and estimated linear curve associating NCCPI and yield (sorghum). Estimated sorghum yield in a particular county with sorghum yield and NCCPI value at ‘A’ is adjusted, using only the b1 value of the estimated relationship, to point ‘B’ by applying the known NCCPI value of CRP lands. Similar relationships were estimated for each of the 8 traditional crops.
model, including crop residues, switchgrass, poplars, and willows.

As laid out in the RFS2, we also assume that the 4 billion gallons of ‘other advanced biofuels’, in addition to the 16 billion gallons of second-generation fuels that are required to be met with cellulosic feedstocks, will be met by other noncellulosic feedstocks or imported (U.S. Environmental Protection Agency, 2010a). This assumption is in line with recent biogas pathways approved by EPA, continued interest in algal biodiesel, advancing technology in the conversion of natural gas for light-duty vehicle transportation fuels, and by continued imports of advanced fuels from abroad. The rapid growth of these alternatives to cellulosic feedstocks indicates that the 4 billion gallons will likely be met by noncellulosic means.

In the baseline scenario, CRP contract holders can either (1) re-enroll, (2) convert to cropland, or (3) convert to pasture usage. In the RFS2-v scenario, CRP contract holders have two additional land-use options: (4) convert to a perennial biomass monoculture (switchgrass, poplars, or willows), or (5) harvest established mixed grasses for biomass. Figure 4 indicates the amount of CRP expiring by year.

Results

Our results will focus on the land conversions that occur to existing CRP lands with and without RFS2, but we will briefly overview the broader picture of land-use impacts of fulfilling RFS2 in order to give the relative role of CRP lands in meeting RFS2. The vast majority of feedstocks to meet the RFS2-v scenario come from crop residues. Crop and forest residues account for 78% of the feedstock quantities, through residue harvesting from 32.26 million hectares of existing corn and wheat lands (i.e., 79% and 40% of current corn and wheat lands). Woody residues from private forest harvesting wastes and thinnings are the second largest feedstock source, accounting for 19% of total feedstocks to meet the RFS2-v scenario. Dedicated biomass on cropland, pastureland, and CRP lands meets only 3% of feedstock demand. Meeting RFS2 would only induce the conversion of 0.27 million hectares of cropland (<1% of total cropland, 2% of feedstock demand), 0.28 million hectares of pastureland (<1% of total pastureland, 0.5% of feedstock demand), and 0.29 million hectares of CRP lands (3% of existing CRP lands, 0.5% of feedstock demand) to biomass generation and harvesting.

Cropland

Figure 5 shows the geographic distribution of commodity acreage losses and gains on existing cropland when moving to the RFS2 scenario. The majority of the 0.27 million hectares of cropland that transition to dedicated biomass crops occur in the Great Plains states of Kansas, Oklahoma, and Texas. Wheat loses the most land to biomass, with the majority of its 0.15 million hectare-loss going to biomass. Corn loses 0.53 million hectares in the RFS2 scenario, but most of this is transitioning to soybeans, and can be accounted for as part of the commonplace corn/soybean rotation. A significant band of wheat and soybean lands along the Piedmont of Virginia and through North Carolina is also converted to biomass crops.

Pasturelands

There are currently over 186 million hectares of pastureland in the USA. When moving to the RFS2-v scenario, only 0.28 million pastureland hectares convert to dedicated biomass (Fig. 6). The greatest concentration of converting pasture occurs in Florida and West Virginia, with scattered pockets of conversion throughout the eastern USA. No pasturelands convert west of the 100th meridian due to the model constraint restricting conversion to pasturelands east of the 100th meridian. The constraint is based on agronomic evidence that in arid regions, there would be inadequate rainfall to yield adequate quantities of biomass (Mitchell et al., 2010).

Prices of the major crops remain fairly stable in comparing the baseline to the RFS2 scenario (Table 2). Dedicated biomass price increases to nearly 52.86 US$ dry Mg⁻¹, compelling the transition of 0.27 million hectares of cropland to dedicated crops. The transition occurs on low productivity lands; therefore, total production of conventional crops is not severely reduced. The extra revenue from residue harvesting on corn and wheat lands keep corn and wheat acreage and prices fairly stable, with less than a 0.5% rise in prices by 2028. Soybeans do not gain the extra revenue from residue harvesting and are therefore the most severely impacted crop in terms of price impacts, with a 6.2% rise in prices by 2028.

CRP lands

In the baseline scenario without RFS2, we estimate that of the 10.24 million hectares of land currently in CRP

![Fig. 4](http://example.com/fig4.png) Year and quantity of CRP lands expiring through 2028.
(25.3 million acres), 5.78 million hectares will re-enroll, 2.75 million hectares will convert to conventional annual crops by 2028, and 1.72 million hectares will convert to perennial hay production (Table 3). In the RFS2-v scenario, we estimate that re-enrollment will decline to 5.58 million hectares, and 2.60 million hectares will convert to conventional annual crops, and 1.78 million hectares will convert to perennial hay production. Payments for dedicated biomass compel 0.29 million hectares to harvest the established grasses for ethanol feedstock. Due to the relatively low cost of harvesting existing biomass, and high initial conversion costs to higher-yielding dedicated biomass production, no CRP lands are converted to dedicated energy crops for ethanol feedstock.

Comparing the two scenarios, meeting the RFS2 would reduce CRP re-enrollment by 0.19 million hectares or 3.7%, below the baseline scenario where RFS2 volumes are not met. Yet under RFS2-v, converted CRP grasslands are less likely to be converted to annual crop production, with 0.29 million hectares of CRP being harvested for biomass. Although less land is enrolled in CRP under RFS2-v, total land in perennial cover increases by 0.15 million hectares under RFS2-v.

Figure 7 shows the estimated geographic conversion of expiring CRP lands by 2028 both with and without RFS2. In the baseline scenario, most of the CRP lands not re-enrolled are in the western USA with pockets of land converting to wheat, barley, oats, and sorghum. Most of the lands estimated to convert to corn and soybeans are east of the 100th meridian. The most significant difference in land use that occurs with RFS2-v is large pockets of lands in the southern plains that are not re-enrolled, and instead, existing biomass is harvested on these lands.

Conversion of CRP lands to annual crop production is most intense in the Cornbelt states stretching into the Red River Valley of North Dakota, with another pocket of intense conversion in the Palouse region of the northwest (Fig. 8). Estimated CRP re-enrollment is most intense, with or without the RFS2, in the arid areas of the west including eastern Colorado, the panhandle regions of Texas and Oklahoma, and northern Montana, but significant re-enrollment is also expected in the Southeast and New England as well. Conversion of CRP lands to dedicated biomass harvesting of existing grasses occurs west of the 100th meridian, such as in western Kansas down into the Panhandle of Texas.
Sensitivity analysis

CRP rental rates. A key parameter subject to variation in implementation is CRP rental rates. We test the sensitivity of our results to changes in rental rates by varying rental rates by $\pm 25\%$ in both the baseline and RFS2 scenarios. Figure 9 shows that with a $25\%$ decline in rental rates, 1.73 million fewer hectares are re-enrolled in CRP compared with current rates of payment, 0.53 million more hectares are converted to annual crops, and 1.15 million hectares more CRP lands are harvested for existing grasses. A $25\%$ increase in rental rates leads to 0.86 million more hectares being re-enrolled with 0.47 million less hectares being converted to annual crops, and the elimination of any production of dedicated perennial energy crops.

Results indicate that the amount of conversion to annual crops is not sensitive to changes in rental rates – with less than a million acre variance under 25% changes in payments. Yet the amount of land either re-enrolled or converted to perennial grass harvesting is very sensitive to CRP rental rates – with differences up to 1.73 million hectares under 25% change in payments. This indicates that for a proportion of CRP lands, their profitability is quite certain, and differences in payment rates will not have much impact on swaying land use. But for a smaller proportion (i.e., the lower yields lands), our results indicate the profitability of many acres is closely matched to either re-enroll in CRP or harvest the existing grasses for biomass. The land use of this second land base can be quite sensitive to small changes to CRP payment rates or market biomass prices.

Variance in yield assumptions. We also test land-use responsiveness to assumptions on yield decline. Our previous method of calculating county-specific crop yield decline on CRP lands using the NCCPI data averages between 20% and 30% for all counties and crops. We test the sensitivity of our previous method by running the model several times assuming different levels of crop yield decline under the RFS2 scenario. We run the model with universal crop yield declines of 10%, 20%, 30%, 40%, and 50% from county-level average crop yields.

Estimates of the amount of CRP lands converting to annual crops vs. being re-enrolled are very sensitive to the assumptions we make on yield decline on returning CRP lands. Our methodology using NCCPI indicates a range from 20% to 30% yield decline (Table 1). If actual yield declines (or rather the yields farmers believe they can achieve) are less than this, then more land will be converted to annual crops. If actual yield declines are greater than our estimates, then less land will convert to annual crops and more will be re-enrolled. Conversion to perennial hay production follows the same trend as conversion to annual crops and declines as yield decline assumptions increase. Across all yield

Table 2 Major crop and biomass prices under baseline and RFS2 scenarios over simulation period

|                        | 2020   | 2024   | 2028   |
|------------------------|--------|--------|--------|
| Corn (US$ Mg\(^{-1}\)) |        |        |        |
| Baseline               | 146.8  | 163.59 | 161.36 |
| RFS2                   | 147.33 | 163.33 | 162.15 |
| % Change               | 0.36   | -0.16  | 0.49   |
| Soybeans (US$ Mg\(^{-1}\)) |        |        |        |
| Baseline               | 346.03 | 368.56 | 364.03 |
| RFS2                   | 346.52 | 369.41 | 386.56 |
| % Change               | 0.14   | 0.23   | 6.19   |
| Wheat (US$ Mg\(^{-1}\)) |        |        |        |
| Baseline               | 174.36 | 195.05 | 199.22 |
| RFS2                   | 170.44 | 191.75 | 199.71 |
| % Change               | -2.25  | -1.69  | 0.25   |
| Biomass (US$ dry Mg\(^{-1}\)) |        |        |        |
| Baseline               | 0      | 0      | 0      |
| RFS2                   | 42.63  | 52.61  | 52.61  |

Table 3 Simulated re-enrollment and conversion of expiring CRP acreage by 2028 under baseline scenario and RFS2-v scenario (national totals)

| Scenarios               | Baseline | RFS2-v | Change from baseline |
|-------------------------|----------|--------|----------------------|
| Total CRP land expiring (mil ha) | 10.24    | 10.24  | 0.00                 |
| Converted to annual crops (mil ha) | 2.75     | 2.60   | -0.16                |
| Soybeans                | 2.32     | 1.91   | -0.40                |
| Corn                    | 0.01     | 0.20   | 0.19                 |
| Wheat                   | 0.08     | 0.08   | 0.00                 |
| Barley                  | 0.02     | 0.02   | 0.00                 |
| Sorghum                 | 0.25     | 0.28   | 0.03                 |
| Rice                    | 0.07     | 0.08   | 0.01                 |
| Oats                    | 0.01     | 0.03   | 0.02                 |
| Cotton                  | 0.01     | 0.00   | 0.00                 |
| In perennial landcover (mil ha) | 7.50     | 7.65   | 0.15                 |
| Acres re-enrolled in CRP (mil ha)** | 5.78     | 5.58   | -0.19                |
| Acres converted to perennial crops (mil ha) | 1.72     | 2.06   | 0.34                 |
| To hay                  | 1.72     | 1.78   | 0.06                 |
| To dedicated biomass* | 0.00     | 0.00   | 0.00                 |
| CRP grasses harvested for biomass | 0.00    | 0.29   | 0.29                 |

*Switchgrass, poplar, or willow production.

Sensitivity analysis

CRP rental rates. A key parameter subject to variation in implementation is CRP rental rates. We test the sensitivity of our results to changes in rental rates by varying rental rates by $\pm 25\%$ in both the baseline and RFS2 scenarios. Figure 9 shows that with a $25\%$ decline in rental rates, 1.73 million fewer hectares are re-enrolled in CRP compared with current rates of payment, 0.53 million more hectares are converted to annual crops, and 1.15 million hectares more CRP lands are harvested for existing grasses. A $25\%$ increase in rental rates leads to 0.86 million more hectares being re-enrolled with 0.47 million less hectares being converted to annual crops, and the elimination of any production of dedicated perennial energy crops.

Results indicate that the amount of conversion to annual crops is not sensitive to changes in rental rates – with less than a million acre variance under 25% changes in payments. Yet the amount of land either re-enrolled or converted to perennial grass harvesting is very sensitive to CRP rental rates – with differences up to 1.73 million hectares under 25% change in payments. This indicates that for a proportion of CRP lands, their profitability is quite certain, and differences in payment rates will not have much impact on swaying land use. But for a smaller proportion (i.e., the lower yields lands), our results indicate the profitability of many acres is closely matched to either re-enroll in CRP or harvest the existing grasses for biomass. The land use of this second land base can be quite sensitive to small changes to CRP payment rates or market biomass prices.

Variance in yield assumptions. We also test land-use responsiveness to assumptions on yield decline. Our previous method of calculating county-specific crop yield decline on CRP lands using the NCCPI data averages between 20% and 30% for all counties and crops. We test the sensitivity of our previous method by running the model several times assuming different levels of crop yield decline under the RFS2 scenario. We run the model with universal crop yield declines of 10%, 20%, 30%, 40%, and 50% from county-level average crop yields.

Estimates of the amount of CRP lands converting to annual crops vs. being re-enrolled are very sensitive to the assumptions we make on yield decline on returning CRP lands. Our methodology using NCCPI indicates a range from 20% to 30% yield decline (Table 1). If actual yield declines (or rather the yields farmers believe they can achieve) are less than this, then more land will be converted to annual crops. If actual yield declines are greater than our estimates, then less land will convert to annual crops and more will be re-enrolled. Conversion to perennial hay production follows the same trend as conversion to annual crops and declines as yield decline assumptions increase. Across all yield
decline assumption levels, land converting to perennial grass harvesting is small and stable (Fig. 10).

Variance in residue retention requirements. For residue harvesting, we assume residues must be retained at regionally specific levels estimated by Muth et al. (2011) to assure that wind and rain erosion are kept at tolerable levels and soil carbon is maintained. But, if the required residues were to change, it could change the harvestable residue quantities, land-use changes, and prices to meet RFS2. To test the sensitivity of our results, we ran two additional scenarios where residue retention requirements were (a) increased by 25% and (b) decreased by 25%. The results shown in Table 4 indicate that an increase in retention requirements would lower harvestable crop residues 7% to 153 million Mg and biomass prices would need to increase to $63.5 US$ dry Mg$^{-1}$ to meet RFS2. The higher biomass price (and crop prices) would induce less CRP land to be re-signed and more converting to both annual and perennial uses. Increased retention rates result in a slight net decline in perennial coverage of expiring CRP acreage (from 7.65 to 7.22 mil ha).

Alternatively, in the scenario with a decrease in crop residue retention requirements, more residues can be collected at lower prices, biomass feedstock prices do not need to rise as high to meet RFS2, and more CRP land is re-enrolled. Yet the lower biomass prices lead to less conversion of CRP to perennial uses and slightly

Fig. 7 Simulated conversion of expired CRP lands to alternative land uses by 2028, without and with, RFS2-v implemented. Land-use change density is displayed at the county level.

Fig. 8 Location and intensity of CRP lands; (a) re-enrolling in CRP, (b) converting to annual crop production, or (c) converting or staying in perennial grass production by 2028 under RFS2-v scenario.
more conversion to annual crops. The net result in the 25% retention reduction scenario is also a slight decline in total perennial cover.

Discussion

The large loss of perennial land cover in recent years has focused renewed attention on the importance of remaining CRP contract lands in holding fragile grassland soils in place (Faber et al., 2012). Now, after several years of losing perennial cover, agricultural lands are faced with the additional burden of meeting the goals of the RFS2 over the next decade. US agricultural lands will likely be tasked with supplying feedstock to produce 21 billion gallons of biofuel.

Results of this analysis indicate that meeting volumes specified in the RFS2 would have minimal impact on CRP lands. RFS2 volumes can be met primarily with crop residues and woody residues with little conversion of cropland, pastureland, and CRP lands. Meeting RFS2-volumes would only induce the conversion of 0.27 million hectares of cropland (<1% of total cropland), 0.28 million hectares of pastureland (<1% of total pastureland), and 0.29 million hectares of

![Fig. 9 CRP land conversion in 2028 under 3 rental payment rate assumptions; (a) current payment rate, (b) decreased by 25%, and (c) increased by 25%.

![Fig. 10 Expiring CRP land use in 2028 under varying yield-dock assumptions.

| Scenario                     | 2028 Results                                      |
|------------------------------|--------------------------------------------------|
| Harvested residues (mil dry Mg) | Feedstock price ($/dry Mg) | Converted to annual crops (mil ha) | CRP re-sign-up (mil ha) | Converted to perennial biomass* (mil ha) | Total perennial cover (mil ha) |
| RFS2-v Base Case retention   | 165.0                                            | 52.6                                 | 2.60                     | 5.59                                      | 2.06                          | 7.65                          |
| RFS2-v + 25% in retention    | 153.1                                            | 63.5                                 | 3.04                     | 3.41                                      | 3.81                          | 7.22                          |
| RFS2-v -25% in retention     | 173.9                                            | 45.4                                 | 2.74                     | 5.80                                      | 1.70                          | 7.51                          |

*Hay, CRP biomass harvesting, or switchgrass.
CRP lands (3% of existed CRP lands) to dedicated biomass uses. Meeting RFS2 volumes would reduce CRP re-enrollment by 0.19 million hectares, or 4%, below the baseline scenario where RFS2 is not met. Yet under RFS2-v scenario, expiring CRP lands are more likely to be converted or maintain perennial cover, with 1.78 million hectares of CRP lands converted to hay production, and 0.29 million hectares being harvested for existing grasses. No conversion of CRP lands to dedicated biomass crops, such as switchgrass, are projected to occur.

Although slightly less land is enrolled in CRP under RFS2-v scenario, total land in perennial cover increases by 0.15 million hectares, or 2%, under RFS2-v. This occurs because the economics of land conversion to dedicated biomass are not favorable. Thus, without the RFS2-v demand, conversion to annuals occurs on CRP lands, whereas with the RFS2-v demand, harvesting of existing biomass or hay production occurs, both of which retain perennial cover.

Both our results based on POLYSYS and those of the Regulatory Impact Assessment (RIA) of the RFS2 based on FASOM (United State Environmental Protection Agency, 2010b) simulate little change in the CRP program between baseline and RFS2 volumes, but for distinctly different reasons. The RIA assumed that USDA increased CRP payments to maintain the program at the (then) minimum limit of 32 million acres. Our analysis used updated information from the intervening years (e.g., 2014 Farm Bill), and found that CRP is still not likely to convert, but this time, it was not because of maintained payments. Rather, because the value of cropping activities generated less income than either the CRP program or harvesting of existing biomass, little conversion occurred.

Sensitivity analysis indicates that CRP rental rates can greatly impact the balance between re-enrollment and conversion to dedicated perennial biomass activities, with conversion to annual crops being fairly stable to changes in CRP rental rates. Yet the sensitivity analysis to crop yield-reduction assumptions on returning CRP lands gives a different dynamic, with the amount of land re-enrolled or converted to annual crops being most impacted, and land converted to dedicated perennial biomass being fairly stable across yield-dock assumptions. The results are sensitive to assumptions of crop residue retention requirements. An increase in requirements leads to a drop in CRP re-enrollment, more conversion to both annual, and a slight net decrease in perennial cover. Yet similarly, a decrease in residue retention requirements also leads to a net loss of perennial cover due to a drop in conversion to perennial crops.

Our results indicate that perennial cover slightly increases with fulfillment of RFS2 volumes above baseline projections, due to (a) biomass harvesting of existing grasses yielding a slight profit on some lands and (b) minimal increases in annual crop prices. Annual crop prices do not rise significantly because crop and woody residues are able to fill most of the required feedstocks and there is little land-use change putting pressure on prices. Yet when we increased the residue retention requirements on crop residue harvesting, conversion of cropland to high yielding dedicated biomass crops put enough pressure on land use to increase crop prices, leading to more CRP conversion to annual crops and a slight net decline in total perennial cover.

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