

Potential Environmental Impacts of Increased Reliance on Corn-Based Bioenergy

Christian Langpap and JunJie Wu*

Abstract. This paper integrates economic and physical models to assess a) how rapid increases in agricultural commodity prices, driven by ethanol production and other factors, will affect land use and cropping systems in the U.S. Midwest, and b) how the changes in land use and cropping systems will in turn affect environmental quality in the region. The empirical framework include a set of econometric models that predict land conversion, crop choices, and crop rotations at the parcel level based on commodity prices, land quality, climate conditions, and other physical characteristics at the sites. The predictions are then combined with site-specific environmental production functions to determine the effect of rising commodity prices on nitrate runoff and leaching, soil water and wind erosion, and carbon sequestration. Results suggest that increasing commodity prices will result in large widespread conversions of non-cropland to cropland. Eighty-two percent of the region's pasture and range land will be converted to cropland with \$8 corn. Rising commodity prices will also result in dramatic changes in crop mix and rotation systems in the Midwest. With \$8 corn, the total acreage of corn will increase by 37%, 80% and 141% in the Corn Belt, Lake States and Northern Plains, respectively; the acreage of continuous corn will increase dramatically in every region. These changes in land use and crop mix will have a significant impact on agricultural runoff and environmental quality. Nitrogen leaching and wind erosion will increase in every region and, in most cases, by more than a third with \$8 corn. Nitrogen runoff will also increase significantly in the Corn Belt and the Northern Plains.

Key words: bioenergy, ethanol, corn prices, crop choice, environmental quality.

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The rapid run-up in oil prices, in conjunction with greater emphasis on energy self-sufficiency, has generated significant growth in ethanol production and increased corn acreage in the United States. Crude oil prices, which averaged less than \$20 per barrel in the 1990s, broke the \$100 per barrel mark in December of 2007 and reached \$140 per barrel in June 2008. Additionally, the Energy Policy Act of 2005 mandated that renewable fuel use in gasoline reach 7.5 billion gallons by 2012, and the Energy Independence and Security Act (EISA) of 2007 increased the mandate for renewable fuels to 36 billion gallons by 2022, including 15 billion gallons of ethanol made from grains, primarily corn. The resulting large and rapid expansion of U.S. ethanol production has significantly increased the demand for corn, contributing to sharp increases in commodity prices. The amount of corn planted in 2007, 94 million acres, was the highest since World War II, and it yielded a record crop of 13.2 billion bushels (Martin 2007). Because corn is one of the most water and chemical-intensive crops, increasing corn production has generated growing concern about its potential environmental effects (Secchi and Babcock 2007; Zilberman and Rajagopal 2007).

The objectives of this paper are threefold. First, we examine how increases in commodity prices driven by ethanol mandates will affect land use, including changes in crop mix and conversions of non-cropland to crop production in the U.S. Midwest. Second, we analyze how the changes in land use will affect nitrate runoffs and percolation, soil erosion, and carbon sequestration in the region. Third, we evaluate to what extent the negative environmental impacts of increased corn production could be mitigated by alternative conservation practices, such as lower nitrogen application rates or conservation tillage and by conservation compliance measures such as prohibiting conversions of highly erodible land to crop production. The study

region includes the Corn Belt (Ohio, Illinois, Indiana, Iowa, Missouri), the Lake States (Michigan, Wisconsin, Minnesota), and the Northern Plains (North Dakota, South Dakota, Nebraska, Kansas), which accounted for 54% of the nation's cropland and 86% of the nation's corn acreage in 2002 (USDA 2004).

To achieve the objectives of this paper, we integrate economic and physical models. The economic models consist of a set of parcel-level models that predict crop choice and rotation based on the expected commodity prices, production costs, land quality, weather conditions, and other control variables. The models cover a large geographic region, yet are based on parcel-level data and hence capture the site-specific characteristics and spatial variability needed to accurately assess the environmental effects of land use changes driven by increased biofuel production. The models are estimated using data from the Natural Resources Inventory (NRI), the most comprehensive resource data ever collected in the United States. The inventories are conducted by the USDA Natural Resources Conservation Service to determine the status, condition, and trend of the nation's soil, water, and related resources. Information on nearly 200 attributes was collected at more than 800,000 sites across the continental United States. A set of micro level, discrete choice models are estimated using these data to predict land use choice at each NRI site.

The economic models are then integrated with a set of physical models to evaluate the impacts of land use changes, driven by increased ethanol production, on nitrate runoff, nitrate percolation, soil water erosion, soil wind erosion, and carbon sequestration at each NRI site. The site-specific impacts are aggregated to the polygon and regional level using the acreage expansion factors provided in the NRI dataset.

Previous studies of the potential environmental impacts of biofuels have focused on whether they create net carbon benefits, given the significant amount of fossil energy expended in their production (Pimentel and Patzek 2006; Farrell 2006). However, other environmental impacts, such as agricultural runoff, have not received the same attention. The only exception, to our knowledge, is Secchi and Babcock (2007), who model CRP enrollment in Iowa for different corn prices. Our approach is to use several crop choice models to examine the environmental impacts of increased demand for corn. We also focus on a larger area, which encompasses the majority of corn production in the U.S.

Our results suggest that increasing corn prices will result in large widespread conversions of non-cropland to cropland, as well as substantial increases in continuous corn. These changes in land use will lead to significant increases in nitrate water pollution, soil erosion and loss of soil carbon. These environmental impacts could be mitigated, to some extent, by implementing conservation practices or land use policies, such as no-till or reduced tillage, lower nitrogen application rates, and a ban on converting highly erodible land to crop production.

This paper is organized as follows. The next section presents the economic models for predicting land use choices under alternative prices and policy scenarios. This is followed by a description of the physical models that we use to estimate the environmental impacts of land use changes. Next, we integrate the economic and physical models to evaluate the impact of increased ethanol production on land use and agricultural nonpoint pollution. The results and policy implications are discussed in the last section.

Economic Models

In this section, we first describe the conceptual framework for estimating the land use choice models and then discuss the data and estimation methods. Estimation results are presented at the end of this section.

Modeling Framework

Within our simple framework, a farmer makes land use decisions to maximize his utility. Land use decisions include whether to allocate a parcel to crop production or non-crop activities and, if a parcel is allocated to crop production, which crop to grow. Suppose a farmer can choose among N crops, with $i = 1, 2, \dots, N$ indicating the crop choices and $i = 0$ indicating non-cropping activity. Let $u_{ij}(X_{ij})$ be the utility from land use i on parcel j , where X_{ij} is a vector of variables affecting the expected profit and risk of growing crop i on parcel j , including expected output and input prices, land characteristics, weather conditions, government commodity program provisions, and land uses in previous years (reflecting crop rotation restrictions). Because individual farmers' preferences and farming skills are unknown to the researcher, $u_{ij}(X_{ij})$ can be considered a random variable and be written as

$$(1) \quad u_{ij}(X_{ij}) = X'_{ij}\beta_i + \varepsilon_{ij}, \quad i = 0, 1, 2, \dots, N.$$

where ε_{ij} is a random error term. If the residuals ε_{ij} are assumed to be independently and identically distributed with the extreme value distribution, then the probability that the farmer will choose land use i at parcel j is given by a multinomial logit model (Maddala 1983):

$$(2) \quad P_{ij} = \frac{e^{X'_{ij}\beta_i}}{\sum_{k=0}^N e^{X'_{ij}\beta_k}}, \quad i = 0, 1, \dots, N.$$

For estimation purposes, it is convenient to rewrite the probability as follows:

$$(3) \quad P_{0j} = P_j(\text{noncrop}) = \frac{e^{X'_{0j}\beta_i}}{\sum_{k=0}^N e^{X'_{ij}\beta_k}},$$

$$(4) \quad P_{ij} = P_j(i | \text{crop}) \cdot P_j(\text{crop}) = \frac{e^{X'_{ij}\beta_i}}{\sum_{k=1}^N e^{X'_{ij}\beta_k}} \cdot \frac{\sum_{k=1}^N e^{X'_{ij}\beta_k}}{\sum_{k=0}^N e^{X'_{ij}\beta_k}}, \quad i = 1, \dots, N.$$

This decomposition is convenient as it means that we can separately study the major land use decision (crop vs. noncrop) and the crop choice decision (which crop to grow, conditional on the parcel being allocated to crop production). The major land use decision can be estimated as a standard logit model and the crop choice decision can be estimated as a multinomial logit model.

The multinomial logit model has been widely used in economic analysis, including the study of the choice of transportation modes, occupations, asset portfolios, and the number of automobiles demanded. In agriculture, it has been used to model farmers' land allocation decisions (Lichtenberg 1989; Wu and Segerson 1995; Hardie and Parks 1997; Plantinga, Mauldin, and Miller 1999), the choice of irrigation technologies (Caswell and Zilberman 1985), and the choice of alternative crop management practices (Wu and Babcock 1998)¹.

Alternatively, one can model the major land use decisions and crop choices as a two-stage nested logit; in the first stage, a farmer must decide whether or not to allocate a parcel to crop production, and in the second stage, he must choose which crop to grow if he decides to allocate the parcel to crop production. The main advantage of a nested logit approach in this case

¹ An often-cited limitation of the multinomial logit model is the assumption of independence of irrelevant alternatives. This assumption imposes a restriction that the relative choice probabilities for any two alternatives are independent of the other choices available. This property is convenient for estimation, but legitimate only if there are no omitted variables in estimation, as omitted variables that are correlated across the choice will result in its violation. Nested logit models are a commonly employed way to relax this assumption, but they require that the analyst impose the correlation pattern *ex ante*. Multinomial probit models are no panacea either as restrictions on the variance-covariance matrix must also be imposed prior to estimation. Although some progress has been made on the estimation of multivariate probit models, existing results are not sufficient to allow accurate and efficient evaluation of even trivariate integration in a sample of even moderate size (Greene 2000).

is that there is a clear nesting structure, which would allow a tractable generalization of the multinomial model. The main disadvantages are the added complexity in conducting simulations and the computational cost given the relatively large size of our data set.

Data and Variable Construction

Because of the substantial differences in weather conditions and cropping systems among the three regions (the Corn Belt, Lake States, and Northern Plains), separate land conversion and land use choice models are estimated for each region. The estimation requires a substantial amount of data, which must be integrated from multiple sources. These data include a) the land use choice at each NRI site, b) farmers' expected output and input prices, c) government commodity program provisions, and d) site characteristics at each NRI point (soil properties, topographic features, climate conditions). In this subsection, we describe the data sources and construction of the variables used in model estimation.

Time-series data on land use choice at each NRI site were derived from the 1982, 1987, and 1992 NRIs. Our study includes 204,000 NRI sites, of which 143,427 (70%) are in cropland (both cultivated and non-cultivated), 25,268 (12%) in pastureland, and 35,305 (18%) in rangeland. Each NRI site was assigned a weight called the xfactor to indicate the acreage it represents. For example, the sum of xfactors at all NRI sites planted to corn gives an estimate of corn acreage in the region. The sampling design ensures that inferences at the national, regional, state, and substate levels can be made in a statistically reliable manner.

Each NRI contains crop choice information for four years (the current year plus the previous three years). Thus, we have crop choice information for 12 years at each NRI site. Pooling these time-series and cross-sectional data results in hundreds of thousands of

observations for the crop choice model in each region. For computational feasibility, we randomly selected five percent of the observations for the estimation of the crop choice models.

Several approaches have been used to estimate farmers' expected prices. Gardner (1976) and Just and Rauser (1981) argued for the use of futures prices in acreage response analysis on rational expectations grounds as well as for forecast accuracy. Chavas and Holt (1990) used adaptive expectations and the lagged market price to model farmers' expected prices. Chavas, Pope, and Kao (1983) examined the role of futures prices, lagged market prices, and support prices in acreage response analysis. They found that since futures prices and lagged market prices are highly correlated and reflect similar market information, use of both in supply equations may lead to multicollinearity, while deleting one of the two makes little empirical difference. Shumway (1983) defined the expected price as the higher of the current weighted support price and a geometric lagged function of market prices in the previous seven years. Wu and Segerson (1995) specified expected prices for program crops as the higher of the current target price and a linear function of previous years' market prices. The number of years lagged is determined using a partial autocorrelation coefficient method.

Based on these studies, the expected price for corn was specified as the higher of the weighted target price and the average futures price in the corn planting season. The weighted target price is calculated by multiplying the corn target price by the portion of corn base permitted for corn planting (i.e., 1-Acreage Reduction Program (ARP) rate for corn). The ARP rate and target price for corn were taken from Green (1990) and other U.S. Department of Agriculture publications. The average futures price for corn in its planting season was estimated as the average of the first and second Thursday closing prices in March at the Chicago Board of Trade (CBT) for December corn. Soybean is a non-program crop. Expected prices for soybeans

were specified as the average futures prices in its planting season, which was estimated as the average of the first and second Thursday closing prices in March on the Chicago Board of Trade (CBT) for November soybeans. Hay is a multi-year, non-program crop. Market prices lagged one year are used as farmers' expected prices for hay. State-level, annual average market price for hay was taken from Agricultural Statistics (U.S Department of Agriculture). Input prices included in the model include the indexes of prices paid by farmers for seeds, agricultural chemicals, and wage rates. All prices are normalized by the current year index of prices paid by farmers for production, interest, taxes, and wage rates (U.S. Department of Agriculture 1999).

Crop yields at individual NRI sites are unavailable for the study region. However, the National Agricultural Statistics Service (NASS)'s county-level, time-series crop data allow us to estimate farmers' expected yields and yield variance in each county. Specifically, following Chavas and Holt (1990), a trend model of $y = \alpha + \beta t + \varepsilon$ was estimated in each county using the NASS data. The resulting predictions were taken as expected yields. The estimated residuals were then used to generate the variances of yields, which are assumed to be constant over time.

To capture the yield differences among NRI sites, physical variables reflecting land quality at individual NRI sites are included as independent variables in the models. NRI provides information on land capability classes and land slope at each NRI site. Slope is a continuous variable measured as a percentage. High quality land is a dummy variable defined as land with a land capability class of 1 or 2. Low-quality land is defined as land with a land capability class above 4. In addition, each NRI sample site is linked to the NRCS's SOILS5 database, providing detailed soil profile information from soil surveys. From the data, average measures of soil properties for top soil layers were calculated. These include average organic matter percentage, clay percentage, soil pH, and permeability. Finally, historical weather data from weather stations

across the study region were obtained from the Midwestern Climate Center. The average of the means and variances of maximum and minimum daily temperatures and precipitation during corn, soybean and wheat growing seasons was estimated for each NRI site using data from the nearest weather station. Because the long-run average of weather conditions changes little over time, farmers' expectations of weather conditions were assumed to be constant and were represented by the averages of the means and variances of temperatures and precipitation during the corn, soybean, and wheat growing seasons from 1975 to 1992.

Model Estimates and Interpretation

The first step in our analysis is to estimate a logit model for the decision to convert non-cropland (pasture or range land) to crop land in each of the three regions using the framework and data described above. The dependent variable is set equal to one if the parcel is used for crops, and to zero otherwise. The elasticities of the probability of a parcel being allocated to crop production in the three regions are shown in table 1. The models correctly predict land use choice at 86 percent, 85 percent, and 78 percent of in-sample sites in the Corn Belt, Lake States, and Northern Plains, respectively.

The main variables of interest in these models are crop prices. The elasticities in table 1 suggest that a 1% increase in the expected price for corn leads, on average, to a 0.2%, 0.1% and 0.4% increase in the probability that a parcel is converted to cropland in the Corn Belt, Lake States and Northern Plains, respectively. A parcel is more likely be allocated to crop production in areas where expected yields for corn are high and mean maximum daily temperatures during corn growing season are low. Precipitation has different effects in the northern plains than in the Corn Belt and Lake States. An increase in the mean precipitation during corn growing season increases the probability of a parcel being allocated to cropland in the Northern Plains, but

decreases the probability in the other two regions, presumably because the Corn Belt and Lake States have much larger rainfall than the Northern Plains. Finally, as expected, parcels with high land quality are more likely to be allocated to crop production, while parcels with low land quality are more likely to be allocated to non-crop activities.

Next, a multinomial logit crop choice model is estimated for each region. For review purposes, the coefficients and marginal effects of the models are presented in Tables A1- A6 in the appendix (available for readers upon request). The models correctly predict crop choice at 66%, 66%, and 53% of sample sites in the three regions, respectively. Furthermore, 92%, 90% and 80% of actual choices in the sample sites in the three region are predicted as the first or second choice by the models.

Tables 2-4 present the elasticities of the probabilities of choosing alternative crops in the three regions, estimated using the model coefficients and the sample means of the variables². The results of particular interest are the elasticities with respect to the expected commodity prices. As shown in tables 2-4, all own-price elasticities are positive, indicating an increase in the expected price for a crop will increase the likelihood that the crop will be planted. However, consistent with previous studies, most price elasticities are inelastic (Wu et al 2004). Thus, crop choice in the study region is relatively unresponsive to changes in the price variables. This is not surprising, in view of agronomic (rotational) constraints and the relatively few crops grown in the study region.

² To determine the effect of land quality and other dummy variables on the choice of crops and tillage practices, we calculate elasticities with respect to these dummy variables as if they were continuous. Specifically, the following formula is used to calculate the elasticities with respect to these dummy variables:

$$\varepsilon \equiv \frac{\partial P_i}{\partial D} \frac{\bar{D}}{P_i} = \bar{D} \left(\hat{\beta}_i^D - \sum_{k=1}^N \hat{P}_k \hat{\beta}_k^D \right),$$

where \bar{D} is the mean of D in the sample (i.e., the percent of NRI points where $D=1$), and $\hat{\beta}_i^D$ is the coefficient on D in equation i . It is necessary to calculate these elasticities because the sign of the coefficients on these dummy variables does not indicate how land quality or other dummy variables affect crop and tillage choices.

The elasticities with respect to the climate variables indicate climate changes have different impacts in the three regions. For example, although an increase in the average maximum daily temperature during the corn growing season increases the likelihood that corn is planted in the Lake States, it reduces the likelihood that corn is planted in the Corn Belt and Northern Plains. Likewise, although an increase in the average precipitation during the corn growing season increases the likelihood that corn is planted in the Corn Belt and Lake States, it reduces the likelihood that corn is planted in the Northern Plains. Land quality also affects crop choice. It seems that fine-textured soils are more likely to be planted to corn, while steep land is less likely to be planted to soybeans because it is an erosion-prone crop.

To capture the rotational constraints, dummy variables of indicating the crop grown on the site in the previous year are included to reflect the influence of crop rotation on the selection of current year's crop. As shown in the appendix, almost all the coefficients on these dummy variables are statistically significant. The marginal effects show that if the previous year's crop is corn, farmers are more likely to grow corn or soybeans; however, if the previous crop is soybeans, farmers are more likely to grow corn, but less likely to grow soybeans. These results reflect the fact that continuous corn and corn-soybean rotation are the most popular cropping systems in the study region, while continuous soybeans is not widely practiced.

Finally, to capture the differences across the landscape in each region that are not reflected by the independent variables (e.g., cultural practices), the Major Land Resource Area (MLRA) dummies are used in the models of the Corn Belt and Lake States.³ In the Northern Plains, the state dummies for North and South Dakota are included because most MLRA dummies are statistically insignificant.

³ Each MLRA is characterized by particular patterns of soil, climate, water resources, land use and type of farming.

Environmental Production Functions

Rapid increases in commodity prices, driven by ethanol mandates, have the potential to dramatically change the landscape in the Midwest. These changes will affect nitrate runoff, nitrate percolation, soil water erosion, soil wind erosion, and carbon sequestration in the region. Following Wu et al. (2003) and Wu and Babcock (1999), we use environmental production functions to predict changes in agricultural externalities. The environmental production functions are estimated using a metamodeling approach (Wu and Babcock 1999). Specifically, for a sample of NRI points, the Erosion Productivity Impact Calculator (EPIC) (Sharpley and Williams 1990) is used to simulate environmental impacts based on crop management practices (crop rotation, tillage, and conservation practices), soil characteristics, and climatic factors at that site. Environmental production functions are then estimated by regressing the simulated environmental data (e.g., measures of nitrate runoff and leaching) on the vector of crop management practices and site characteristics using appropriate models and econometric methods. For example, Wu and Babcock (1999) use a generalized Tobit model to estimate the nitrate-N runoff and percolation production functions to account for heteroskedasticity and censoring problems. The estimated environmental production functions are then used to predict environmental impacts at the full set of NRI points. These functions use the same information as the simulation model, but they eliminate the need to conduct model simulations for all input combinations, since they predict the outcome of such simulations. Metamodeling is required because it is not feasible to simulate environmental impacts at all sites and for all sets of conditions that arise in a large regional analysis such as performed here. Furthermore, metamodels simplify the analysis of changes in crop management practices because instead of

conducting new simulations, regression coefficients can reveal how changes affect predicted outcomes.

The nitrate runoff and percolation production functions are taken from Wu and Babcock (1999). The methodologies used to develop the erosion and carbon sequestration production functions, similar to those used in this analysis, are described in Lakshminarayan, Babcock, and Ogg (1996) and Mitchell et al. (1998), respectively. Environmental production functions of the type used here have been applied in Gassman et al. and Wu and Babcock (1999).

The site-specific impacts measured at each NRI site are aggregated to the polygon and regional level using the acreage expansion factors provided in the NRI dataset. The polygons represent unique intersections of county, major land resource area, and hydrologic unit boundaries, and are the least aggregated level at which NRI data can be reported.

Potential Environmental Impacts of Ethanol Mandates

The preceding sections describe a set of land use and environmental performance models that collectively form an assessment framework. In this section we apply this framework to evaluate how changes in commodity prices, driven by increased ethanol production, will affect land use and agricultural nonpoint source pollution in the Midwest.

We first establish a baseline for the evaluation. The baseline includes three years because environmental impacts of land use depend not only on crop choice, but also on crop rotations. For example, continuous corn uses between 175% and 250% more nitrogen fertilizer than corn following soybeans. Likewise, the corn-corn-soybean rotation and the corn-soybean rotation may also have different environmental impacts. To determine crop rotations at each NRI point in the baseline, we must determine crop choices in three consecutive years at each NRI site. In this study, we use the historical mean of commodity prices between 1982 and 2005 to determine crop

rotations and levels of agricultural pollution in the baseline (see table 5). We chose this time frame to include the earliest year in which NRI data are available (1982) and to extend up to the passage of the Energy Policy Act of 2005. This is the first federal law mandating minimum amounts of ethanol for production of gasoline.

Land uses and crop rotation at each NRI point in the baseline are established using the following procedure. First, we use the major land use choice model to predict which NRI parcels will be used for crops⁴. Next, for the parcels designated as cropland, we calculate the probabilities of choosing alternative crops in the first baseline year by substituting historical average prices into the crop choice models. Based on the predicted probabilities, we then use a random number generator to determine crop choice at each NRI site in the first baseline year. Once the crop choice in the first year is determined, we determine crop choices in the second year, and then repeat the process for the third year. Finally, based on the crop choices in the three baseline years, we determine crop rotation at each NRI site in the baseline. For example, if corn is chosen each year at an NRI site, we have continuous corn at that NRI site. The spatial patterns of land use acreage and cropping systems generated this way are generally consistent with the historical averages for the period 1982-2005, although the crop choice model for the Northern Plains over-predicts wheat acreage relative to the historical mean.

The baseline levels of agricultural pollution are estimated using the environmental production functions. Specifically, by substituting the crop rotation and the corresponding level of nitrogen application at each NRI site into the environmental production functions, we estimate the level of nitrate runoff, nitrate percolation, soil water erosion, soil wind erosion, and carbon sequestration at each NRI site in the baseline. The site-specific measures of environmental

⁴ Parcels are designated as crop land if the predicted probability that the site will be used for crops is greater than 0.5.

impacts are aggregated to the polygon or regional levels using the expansion factor to facilitate presentations of the results.

The baseline serves as a benchmark for evaluating the environmental impacts of increased ethanol production. We consider three scenarios, based on three alternative future prices for corn: \$4, \$6, and \$8 per bushel, as listed for corn futures on the Chicago Board of Trade (CBT) between January and June 2008. In each of these scenarios we also allow the prices of other crops in our models to change (see table 3). The corresponding prices for soybeans and wheat are obtained from futures prices (for the same dates) listed on CBT. For sorghum and hay, we assume that the initial ratio to the price of corn remains constant and use this ratio to predict the corresponding prices for these crops in each scenario. To be able to isolate the effects of changes in crop prices in the simulations, we keep the input prices constant at baseline levels.

The land use choices, crop rotations and the levels of environmental impacts under each of the scenarios are estimated in the same way as in the baseline. Specifically, we first estimate crop choices and crop rotation at each NRI site under each scenario using the crop choice models and then estimate the environmental impacts at each NRI site using the environmental production functions. Finally, we compare the results under each scenario with the baseline to determine the impacts of increased ethanol production and commodity prices.

This approach to analyzing the environmental effects of increased commodity prices driven by ethanol production has certain limitations. For instance, other factors may have contributed to the increases in crop prices. If so, our results cannot pinpoint and reveal how much of the environmental impacts are caused by ethanol production. Nevertheless, this analysis provides insight into potential impacts of increased reliance on corn-based ethanol which thus far have not entered the debate surrounding biofuels.

The land use and environmental impacts of increased commodity prices are presented in tables 6-8. The tables show the three-year average of acres of the various crops, non-cropland (range and pasture), and land enrolled in the CRP, total acreage of land in various crop rotations, total nitrogen runoff and percolation, total wind and water erosion, and total loss of soil carbon for each of the three regions in the baseline and for the three price scenarios. Baseline differences in the environmental quality measures between regions reflect different total acreage in each region as well as variation in per-acre values of these measures. For instance, both mean nitrate runoff and percolation per acre are higher in the Corn Belt than in the Northern Plains. On the other hand, mean wind erosion per acre is much higher in the Northern Plains than in the other two regions.

The simulation results suggest that rising prices would result in large widespread conversions of non-cropland to cropland. There are a total 58 million acres of pasture and range land in the study region. 82% of those lands (or 48 million acres) will be converted to cropland when corn prices rise to \$8. Most of the conversions (about 43 millions) will take place in the Northern Plains because there are relatively few acres of pasture and range land in the Corn Belt and the Lake States.

Rising commodity prices will also result in dramatic changes in crop mix and rotation systems in the Midwest. With \$8 corn, the total acreage of corn will increase by 37%, 80% and 141% in the Corn Belt, Lake States and Northern Plains, respectively. The smaller percent increase in the Corn Belt reflects the large corn base in the region. Sixty-three percent of corn acres in the study region are located in the Corn Belt. In addition to the changes in crop mix, cropping systems also adjust with rising commodity prices. The acreage of continuous corn increases dramatically in every region with \$8 corn, with the largest percentage increase in the

Northern Plains. The effect on the remaining rotations varies by region. In the Corn Belt and the Northern Plains where corn-soybeans rotations are popular (in terms of the relative percentages of continuous corn and corn-soybeans rotations), the acreage of corn-soybeans rotations also increases. In the Lake States where corn-soybeans rotations are less popular, these cropping systems will be switched to continuous corn. The only exception is the acreage involving a corn-corn-alfalfa rotation, which also increases in the Lake States. In the Northern Plains, acreage planted in continuous sorghum also increases with rising commodity prices.

The results in tables 6-8 indicate that the conversions of non-cropland to cropland and the changes in crop mix and rotational systems, driven by rising commodity prices, will have a significant impact on agricultural runoff and environmental quality. Nitrogen leaching and wind erosion will increase in every region and, in most cases, by more than a third with \$8 corn. Nitrogen runoff will also increase significantly in the Corn Belt and the Northern Plains. However, in the Lake States, nitrogen runoff decreases by 7.8% because of switching from the cropping systems involving corn-soybean rotations to continuous corn, which is less prone to runoff and corn-soybeans rotations. Loss of soil organic carbon increases in the Corn Belt and the Lake States, but decreases in the Northern Plains. Hence, our results suggest that, with some exceptions in particular regions, changes in land use driven by increased commodity prices, as already reflected in futures contracts, will lead to significant increases in nitrate water pollution, soil erosion, and soil organic carbon losses. Next, we explore some policy options to mitigate these environmental effects.

Mitigation Policies

The environmental effects described in tables 6-8 could be mitigated through conservation practices and land use policies. Here we briefly analyze the potential impacts of three such

policies: adoption of no-till practices, reducing nitrogen application rates, and a ban on converting highly erodible land to crop production. The potential benefit from adopting no-till practices is assessed by assuming that it is implemented on all cropland. The effectiveness of reducing nitrogen application rates as a mitigation measure is assessed by reducing nitrogen-application rates by 10%. Finally, to simulate a ban on converting highly erodible land, we identify the parcels that are not in cropland in the baseline and have an erodibility index of eight or higher, and we restrict the crop choice models so that no crop is assigned to those parcels⁵. We conduct simulations for each of these policies using the procedure described above and a price of corn of \$6/bushel, and we compare the outcomes to those of a “no-mitigation” scenario (which corresponds to the \$6/bushel results in tables 6-8). Table 9 shows the values of the environmental quality measures for the baseline, the no-mitigation scenario, and each of the three policies in all three regions (the percentage changes are all relative to the baseline). Our objective here is not to conduct an exhaustive evaluation of policy alternatives, but rather to provide some basic insight into the extent to which the negative environmental impacts from increased ethanol production could be mitigated through commonly suggested conservation practices and land use policies.

The results in table 9 suggest that, although there is some variation across regions, these policies could in general be effective in mitigating the environmental impacts of ethanol-driven increases in corn production. Specifically, compared to the no-mitigation scenario, a no-tillage policy would be effective in reducing the impacts on nitrogen runoff, carbon sequestration, and wind and water erosion. A reduction in nitrogen application rates could be used to mitigate the impacts on nitrogen runoff and percolation. Finally, a ban on converting highly erodible land

⁵ The Natural Resource Conservation Service defines highly erodible land as land which has an erodibility index of eight or more (see <http://www.nrcs.usda.gov/Technical/NRI/maps/meta/m5997.html>).

would be effective in reducing the impact on nitrogen runoff and percolation, and to some extent on wind erosion.

Concluding Comments

Rapidly increasing oil prices and federal and state legislations mandating minimum amounts of corn-based ethanol have contributed to significant increases in the demand for corn and record high prices of corn and other agricultural commodities. These price increases will have considerable impacts on land use and crop choices, and therefore on environmental quality. This study presents an empirical modeling framework designed to assess these effects over a large area of the Midwest (the Corn Belt, Lake States, and Northern Plains), which produce more than 85% of corn in the U.S.

The empirical models developed in this study predict land conversion, crop choices, and crop rotations at NRI sites in the region based on commodity prices, land quality, climate conditions, and other physical characteristics at each of the NRI sites. The data on crop rotations, nitrogen application rate, tillage practices, land quality and other physical characteristics are then combined with site-specific environmental production functions to determine the effect of rising corn prices on nitrate runoff and leaching, soil water and wind erosion, and carbon sequestration at each NRI site. Finally, we use our empirical models to explore the extent to which the negative environmental impacts associated with land use changes could be mitigated through conservation practices and land use policies.

Our results suggest that increasing commodity prices will result in large widespread conversions of non-cropland to cropland. Eighty-two percent of the region's pasture and range land will be converted to cropland with \$8 corn. Most of the conversions (about 43 millions)

will take place in the Northern Plains because there are relatively few acres of pasture and range land in the Corn Belt and the Lake States. Rising commodity prices will also result in dramatic changes in crop mix and rotation systems in the Midwest. With \$8 corn, the total acreage of corn will increase by 37%, 80% and 141% in the Corn Belt, Lake States and Northern Plains, respectively; the acreage of continuous corn increases dramatically in every region, with the largest percentage increase in the Northern Plains.

These changes in land use and crop mix and rotational systems will have a significant impact on agricultural runoff and environmental quality. Nitrogen leaching and wind erosion will increase in every region, and in most case, by more than a third with \$8 corn. Nitrogen runoff will also increase significantly in the Corn Belt and the Northern Plains. These environmental impacts could be mitigated through adoption of conservation tillage, reduction in nitrogen application rates, and implementation of conservation compliance measures such as a ban on converting highly erodible land to crop production.

References

- Antle, J.M., and S.M. Capalbo. "Econometric-Process Models for Integrated Assessment of Agricultural Production Systems." *American Journal of Agricultural Economics* 83(2001):389-401.
- Ashraf, M., C.H. Pearson, D.G. Westfall, and R. Sharp. "Effect of Conservation Tillage on Crop Yields, Soil Erosion, and Soil Properties under Furrow Irrigation in Western Colorado." *American Journal of Alternative Agriculture* 14(1999):85-92.
- Bain, L.J., and M. Engelhardt. *Introduction to Probability and Mathematical Statistics*. Belmont, CA: Duxbury Press, 1992.
- Caswell, M., and D. Zilberman. "The Choice of Irrigation Technologies in California." *American Journal of Agricultural Economics* 67(1985):224-34.
- Chavas, J., and M. T. Holt. "Acreage Decisions Under Risk: The Case of Corn and Soybeans." *American Journal of Agricultural Economics* 72(August 1990): 529-538.
- Chavas, J., R. D. Pope, and R. S. Kao. "An Analysis of the Role of Future Prices, Cash Prices, and Government Programs in Acreage Response." *Western Journal of Agricultural Economics* 8(1983):27-33.
- Cooper, J.C., and R.W. Keim. "Incentive Payments to Encourage Farmer Adoption of Water Quality Protection Practices." *American Journal of Agricultural Economics* 78(1996): 54-64.
- Ervin, C.A., and D.E. Ervin. "Factors Affecting the Uses of Soil Conservation Practices: Hypotheses, Evidence, Policy Implications." *Land Economics* 58(1982):277-92.
- Farrell, A. E., R. J. Plevin, B. T. Turner, A. D. Jones, M. O'Hare, and D. M. Kammen. "Ethanol Can Contribute to Energy and Environmental Goals," *Science* 311, 5760 (2006):506-508.
- Fuglie, K.O., and D.J. Bosch. "Economic and Environmental Implication of Soil Nitrogen Testing: A Switching-Regression Analysis." *American Journal of Agricultural Economics* 77(1995):891-900.
- Fleming, R., and R. M. Adams. "The Importance of Site-Specific Information in the Design of Policies to Control Pollution." *Journal of Environmental Economics and Management* 33(1997):347-358.
- Gardner, B.L. "Futures Prices in Supply Analysis." *American Journal of Agricultural Economics* 58(1976):81-84.

- Gassman, P.W., J.J. Wu, P. Mitchell, B.A. Babcock, T.M. Hurley, and S.W. Chung. "Impact of U.S. Agricultural Policy on Regional Nitrogen Losses." *Proceedings of the 3rd International Conference on Diffuse Pollution* (Poster Papers), 31 Aug. - 4 Sept. 1998, Edinburgh, Scotland. International Association of Water Quality, London, England. pp. 115-22.
- Green, R.C. "Program Provisions for Program Crops: A Database for 1961-90." Agriculture and Trade Analysis Division, Economic Research Service, U.S. Department of Agriculture. Staff Report No. AGES 9010. March 1990.
- Greene, W.H. *Econometric Analysis*. Fourth Edition. New York: Macmillan Publishing Company, 2000.
- Hallberg, G.R. "Nitrate in Ground Water in the United States." *Nitrogen Management and Ground-Water Protection*, R.F. Follet, ed., pp. 35-74. New York: Elsevier Science Publishing Co., 1989.
- Hardie, I. W. and P. J. Parks, "Land Use with Heterogeneous Land Quality: An Application of an Area Base Model." *American Journal of Agricultural Economics* 79 (1997), 299-310.
- Helfand, G.E., and B.W. House. "Regulating Nonpoint Source Pollution Under Heterogeneous Conditions." *American Journal of Agricultural Economics* 77(1995):1024-32.
- Helms, G.L., D.V. Bailey, and T.F. Glover. "Government Programs and Adoption of Conservation Tillage Practices on Nonirrigated Wheat Farms." *American Journal of Agricultural Economics* 69(1987):786-95.
- Hochman, E., and D. Zilberman. "Examination of Environmental Policies Using Production and Pollution Microparameter Distribution." *Econometrica* 46(1978): 739-60.
- Johnson, S.L., R.M. Adams and G. M. Perry. "The On-Farm Costs Of Reducing Groundwater Pollution." *American Journal of Agricultural Economics* 73(1991):1063-72.
- Just, R. E., and J.M. Antle. "Interactions Between Agricultural and Environmental Policies: A Conceptual Framework." *American Journal of Agricultural Economics* 80(1990):197-202.
- Just, R.E., and G.C. Rausser. "Commodity Price Forecasting with Large-Scale Econometric Models and the Futures Market." *American Journal of Agricultural Economics* 63(1981):197-207.
- Kellogg, R. L., M. S. Maizel, and D. W. Goss. "Agricultural Chemical Use and Groundwater Quality: Where are the Potential Problem Areas?" Soil Conservation Service, USDA, Washington DC, December 1992.

- Korsching, P.F., C.W. Stofferahn, P.J. Nowak, and D. Wagener. "Adoption Characteristics and Adoption Patterns of Minimum Tillage: Implications for Soil Conservation Programs." *Journal of Soil and Water Conservation* 38(1983):428-30.
- Kurkalova, L.A., C.L. Kling, and J. Zhao. "The Subsidy for Adopting Conservation Tillage: Estimation from Observed Behavior." Working Paper 01-WP 286, Center for Agricultural and Rural Development, Iowa State University, September 2001.
- Lakshminarayan, P.G., B.A. Babcock, and C. Ogg. "Temporal and Spatial Evaluation of Soil Conservation Policies." Working Paper 96-WP 149, Center for Agricultural and Rural Development, Iowa State University, February 1996.
- Lichtenberg, E.. "Land Quality, Irrigation Development, and Cropping Patterns in the Northern High Plains." *American Journal of Agricultural Economics* 71(1989):187-94.
- Maddala, G.S. *Limited-Dependent and Qualitative Variables in Econometrics*. Cambridge: Cambridge University Press, 1983.
- Martin, A. "Food and Fuel Compete for Land." *The New York Times*. December 18, 2007.
- McFadden, D. "Quantal Choice Analysis: A Survey." *Annals of Economic and Social Measurement* 5(1976):363-90.
- Mitchell, P.D., P.G. Lakshminarayan, T. Otake, and B.A. Babcock. "The Impact of Soil Conservation Policies on Carbon Sequestration in Agricultural Soils of the Central U.S.", in R. Lal, J.M. Kimble, R.F. Follett, and B.A. Stewart, Eds., *Management of Carbon Sequestration in Soil*, CRC Press, Boca Raton, FL, 1998.
- Mitsch, W.J., J.W. Day, Jr., J.W. Gilliam, P.M. Groffman, D.L. Hey, G.W. Randall, and N. Wang. "Reducing Nitrogen Loading to the Gulf of Mexico from the Mississippi River Basin: Strategies to Counter a Persistent Ecological Problem." *BioScience* 51(2001): 373-88.
- Mueller, D.K., P.A. Hamilton, D.R. Helsel, K.J. Hitt, and B.C. Ruddy. "Nutrients in Ground Water of the United States – An Analysis of Data Through 1992." Water Resources Investigations Report No. 95-4031. U.S. Geological Survey, Denver CO, 1995.
- Napier, T.L., C.S. Thraem, A. Gore, and W.R. Goe. "Factors Affecting Adoption of Conventional and Conservation Tillage Practices in Ohio." *Journal of Soil and Water Conservation* 39(1984):205-208.
- Nielsen, E.G., and L.K. Lee. "The Magnitude and Costs of Groundwater Contamination From Agricultural Chemicals: A National Perspective." U.S. Department of Agriculture, Washington DC. Economic Research Services, Agricultural Economic Report No. 576, October 1987.

- Pimentel, D., and T. Patzek. "Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower." *Natural Resources Research* 14, 1 (2005):65-76.
- Pionke, H.B., and J.B. Urban. "Effect of Agricultural Land Use on Ground-Water Quality in Small Pennsylvania Watershed." *Ground Water* 23(1985):68-80.
- Plantinga, A.J., T. Mauldin, and D.J. Miller. "An Econometric Analysis of the Cost of Sequestering Carbon in Forests." *American Journal of Agricultural Economics* 81 (1999):812-24.
- Secchi, S. and B. A. Babcock. "Impact of High Crop Prices on Environmental Quality: A Case of Iowa and the Conservation Reserve Program." Working Paper 07-WP 447 Center for Agricultural and Rural Development Iowa State University. May 2007.
- Sharpley, A.N., and J.R. Williams, eds. EPIC – Erosion/Productivity Impact Calculator: 1. Model Documentation. Technical Bulletin No. 1768, USDA, Washington DC, 1990.
- Shumway, C.R. "Supply, Demand, and Technology in a Multiproduct industry: Texas Field Crops." *American Journal of Agricultural Economics* 65(1983):748-60.
- Smith, R.A., R.B. Alexander, and M.G. Wolman. "Water Quality Trends in the Nation's Rivers." *Science* 235(1987):1607-15.
- U.S. Department of Agriculture. *Agricultural Statistics*. Washington DC: U.S. Department of Agriculture, annual series, 1975-1999.
- U.S. Department of Agriculture, Economic Research Service. "1995 Cropping Practices Survey Data (93018F)." <http://www.ers.usda.gov/data/sdp/view.asp?f=inputs/93018/F/> (March 2003)
- U.S. Department of Agriculture. *2002 Census of Agriculture*. Washington DC: U.S. Department of Agriculture, 2004.
- Williams, J.R., R.V. Llewelyn, and G.A. Barnaby. "Risk Analysis of Tillage Alternatives with Government Programs." *American Journal of Agricultural Economics* 72(1990):172-91.
- Wu, J., and B.A. Babcock. "Metamodeling Potential Nitrate Water Pollution in the Central United States." *Journal of Environmental Quality* 28(1999): 1916-28.
- Wu, J., and B.A. Babcock. "The Choice of Tillage, Rotation, and Soil Testing Practices: Economic and Environmental Implications." *American Journal of Agricultural Economics* 80(1998):494-511.

Wu, J., and K. Segerson. "The Impact of Policies and Land Characteristics on Potential Groundwater Pollution in Wisconsin." *American Journal of Agricultural Economics* 77(1995):1033-47.

Vetsch, J.A., and G.W. Randall. "Corn Production as Affected by Tillage System and Starter Fertilizer." *Agronomic Journal* 94(2002):532-40.

Zilberman and Rajagopal. "Review of Environmental, Economic and Policy Aspects of Biofuels." Policy Research Working Paper 4341. The World Bank Development Research Group. Sustainable Rural and Urban Development Team (2007)

Table 1. Major Land Use Choose Models - Elasticities of the Probability of Allocating a Parcel to Cropland

Variable	Corn Belt	Lake States	Northern Plains
Expected price for corn	0.205 ^{***}	0.071 ^{***}	0.366 ^{***}
Expected price for hay	0.091 ^{***}	-0.032 ^{***}	0.238 ^{***}
ARP rate for corn	0.080 ^{***}	0.034 ^{***}	0.184 ^{***}
Expected yield of corn	0.540 ^{***}	0.262 ^{***}	0.532 ^{***}
Expected variation of corn yield	-0.016 ^{***}	-0.034 ^{***}	0.045 ^{***}
Mean precipitation corn	-0.7854 ^{***}	-1.554 ^{***}	1.021 ^{***}
Mean precipitation corn ²	0.349 ^{***}	0.645 ^{***}	-0.368 ^{***}
Mean maximum temperature corn	-0.762 ^{***}	-0.010	-2.056 ^{***}
Mean maximum temperature corn ²	0.332 ^{***}	0.012	0.694 ^{***}
Slope	-0.090 ^{***}	0.026 ^{***}	-0.238 ^{***}
Slope ²	0.009 ^{***}	-0.022 ^{***}	0.034 ^{***}
Bad land	-0.006 ^{***}	-0.013 ^{***}	-0.151 ^{***}
Good land	0.012 ^{***}	0.067 ^{***}	0.114 ^{***}
Observations	210,874	86,153	262,000
% correct predictions	86%	85%	78%

Note: *** denotes statistical significance at $\alpha = 1\%$. All elasticities are evaluated at the sample means of variables.

Table 2. The Crop Choice Model for the Corn Belt - Elasticities of Probabilities to Choose Alternative Crops

Variable	Corn	Soybeans	Wheat	Hay	Other
<i>Price and Policy Variables</i>					
Expected price for corn	0.2419	-0.3985	1.4350	0.3916	-0.6431
Expected price for soybeans	-0.1452	0.4069	-1.3602	-0.1831	0.1632
Expected price for wheat	0.1035	-0.1184	0.3125	-0.0858	-0.1202
Expected price for hay	-0.0589	0.0191	0.1626	-0.0365	0.0861
ARP rate for wheat	0.0440	-0.0505	0.2648	0.0599	-0.1665
Fuel price	0.1212	-0.2285	1.8717	-0.3814	-0.4249
Chemical price	-0.5002	0.8443	-3.6059	-0.8928	1.6140
Wage rates	-0.4050	0.6102	-1.0621	-0.1100	0.2981
<i>Expected Yield and Yield Variation of Corn</i>					
Expected yield of corn	0.4382	-0.1749	-0.7699	-0.5067	-0.2985
Expected variation of corn yield	-0.0449	0.1416	-0.3680	0.0183	-0.0563
<i>Land Characteristics</i>					
Good land	-0.0141	0.0279	0.0240	-0.0038	-0.0334
Bad land	0.0024	-0.0062	0.0062	0.0000	0.0050
Slope	0.0245	-0.1004	0.1005	0.0726	0.0840
Available water capacity	0.3046	-0.1754	-0.8031	-0.1154	-0.0943
Organic matter	0.0026	-0.0023	0.0121	-0.0185	0.0030
Soil pH	0.1041	0.0800	0.0361	-0.5735	-0.2021
Coarse-textured soil	-0.0160	0.0418	-0.0495	-0.0218	-0.0184
Fine-textured soil	0.0028	0.0016	-0.0159	-0.0057	-0.0023
<i>Weather Conditions during Corn or Wheat Growing Season</i>					
Mean maximum temperature_corn	-2.0451	2.9159	1.8977	-2.0357	-0.4525
Mean precipitation_corn	0.1743	-0.1817	-1.0619	0.2684	0.2191
St. deviation of precipitation_corn	-0.4535	0.5227	1.2587	-0.3693	-0.2159
Mean of precipitation_wheat	0.0464	-0.0587	0.0335	-0.1045	0.0464
St. deviation of precipitation_wheat	-0.1256	0.1327	-0.2399	0.3613	-0.0405

Note: All elasticities are evaluated at the sample means of variables.

Table 3. The Crop Choice Model for the Lake States - Elasticities of Probabilities to Choose Alternative Crops

	Corn	Soybeans	Wheat	Hay	Other
<i>Price and policy variables</i>					
Expected price for corn	1.2872	-1.2722	0.6650	-0.8418	-0.8199
Expected price for soybeans	-0.7045	0.7085	-1.9206	1.0475	0.2893
Expected price for wheat	-0.0087	-0.0617	0.1169	-0.2384	0.2575
Expected price for hay	0.0477	-0.3312	-0.0498	0.1413	0.0497
ARP rate for wheat	0.1003	-0.1075	0.0658	-0.0505	-0.0749
Fuel price	-0.6461	0.6162	0.6325	-0.1477	0.7146
Chemical price	-0.7339	-0.0037	-2.9237	0.3869	1.7757
Wage rate	0.8637	-1.1676	0.7438	-0.7185	-0.2371
<i>Expected yield and yield variation of corn</i>					
Expected yield of corn	-0.0397	1.5510	-1.1023	-0.5040	-0.3854
Expected variation of corn yield	-0.0879	0.4014	-0.3390	0.0410	-0.0995
<i>Land characteristics</i>					
Good land	0.0404	-0.0222	0.1158	-0.0247	-0.0656
Bad land	0.0043	-0.0101	-0.0105	0.0001	0.0024
Slope	0.0097	-0.1136	0.0839	-0.0028	0.0516
Available water capacity	0.0261	0.1088	-0.0261	0.0664	-0.1898
Organic matter	0.0003	-0.0271	0.0159	-0.0058	0.0219
Soil pH	-0.0748	0.4355	1.4823	-0.2857	-0.3116
Coarse-textured soil	-0.0037	-0.0011	0.0501	0.0017	-0.0065
Fine-textured soil	0.0211	-0.0587	0.0164	-0.0085	0.0097
<i>Weather conditions during the corn growing season</i>					
Mean maximum temperature_corn	0.6652	-0.4682	1.9142	-0.2777	-1.1207
Mean precipitation_corn	0.1331	0.0725	-3.4340	0.4404	0.1590
St. deviation of precipitation_corn	0.2738	-0.3738	1.1817	-0.4239	-0.1312

Note: All elasticities are evaluated at the sample means of variables.

Table 4. The Crop Choice Model for the Northern Plains - Elasticities of Probabilities to Choose Alternative Crops

	Corn	Soybeans	Wheat	Hay	Sorghum	Other
<i>Price and Policy Variables</i>						
Expected price for corn	0.2686	-1.1696	-0.0249	-0.0322	0.9235	-0.1361
Expected price for soybeans	0.2948	0.9310	-0.7372	-0.1909	-0.9690	0.7804
Expected price for wheat	-0.1156	-0.0143	0.0675	0.0745	0.5015	-0.2123
Expected price for hay	-0.2970	-0.1154	0.1867	0.1162	0.0702	-0.0478
Expected price for Sorghum	0.7708	0.1572	-0.5767	-0.3860	0.6954	-0.0453
ARP rate for wheat	0.1435	-0.0223	-0.1117	-0.0706	0.2140	-0.0211
Fuel price	-1.6704	1.0607	1.1153	0.8718	-0.2732	-0.6543
Chemical price	-2.6146	1.7748	0.0408	1.6874	-0.5136	0.7668
Wage rate	-0.4068	0.2738	0.0455	-0.0721	0.7200	-0.1364
<i>Expected Yield and Yield Variation of Corn</i>						
Expected yield of corn	0.6224	0.2394	-0.3903	-0.1095	-0.0221	0.0141
Expected variation of corn yield	-0.2225	0.3954	-0.0043	-0.0496	-0.1193	0.0844
<i>Land Characteristics</i>						
Good land	0.0774	-0.0516	0.0423	-0.0086	-0.0528	-0.0566
Bad land	-0.0032	-0.0086	-0.0070	0.0062	0.0116	0.0061
Slope	0.0464	-0.0160	-0.0964	0.0029	-0.0433	0.0983
Available water capacity	-0.1375	1.1251	-0.0937	-0.1088	-0.2481	-0.0204
Organic matter	-0.1016	0.0484	0.0043	-0.0327	0.0751	0.0240
Soil pH	-0.3611	-1.5486	0.2245	-0.0092	-0.3497	0.5731
Coarse-textured soil	-0.0164	0.0715	-0.0108	-0.0069	0.0239	-0.0065
Fine-textured soil	0.0131	0.0467	-0.0257	0.0019	0.0161	-0.0004
<i>Weather Conditions during the Corn or Wheat Growing Season</i>						
Mean maximum						
temperature_corn	-4.2487	-8.7190	4.6969	-0.3679	4.6622	-1.6513
Mean precipitation_corn	-0.2396	-0.8128	1.0852	0.4256	0.9815	-1.3047
St. deviation of						
precipitation_corn	0.6094	3.7619	-1.8160	-0.1218	-0.4456	0.7142
Mean of precipitation_wheat	0.5118	7.8006	-2.3530	0.0199	-0.2560	0.0531
St. deviation of						
precipitation_wheat	-1.1053	-7.9130	3.4886	-0.1353	-0.1285	-0.7266
Mean of snow_wheat	-0.0498	0.0006	0.0251	0.0533	-0.0042	-0.0104
St. deviation of snow_wheat	0.1646	-0.0411	-0.1064	-0.1518	0.0552	0.0493

Note: All elasticities are evaluated at the sample means of variables.

Table 5. Crop Prices Used in Simulations

Crop	Baseline			Scenario 1	Scenario 2	Scenario 3
	Corn Belt	Lake States	Northern Plains			
Corn	3.13	3.02	3.00	4.00	6.00	8.00
Soybeans	7.90	7.72	7.56	10.97	14.13	20.39
Wheat	4.03	4.13	4.35	8.76	9.92	13.72
Hay	107.57	95.61	76.95	137.3	201.00	272.5
Sorghum			4.75	4.16	6.08	8.25

Table 6. The Estimated Impacts of Higher Commodity Prices on Land Use and Environmental Quality in the Corn Belt

Land Use/Environmental Impacts	Baseline	Scenario 1: \$4 Corn		Scenario 2: \$6 Corn		Scenario 3: \$8 Corn	
		level	% change	level	% change	level	% change
<i>Land Use (1000 acres)</i>							
Acres of Corn	36,523	41,728	14.3	45,730	25.2	50,107	37.2
Acres of Soybeans	36,286	37,584	3.6	37,442	3.2	38,127	5.1
Acres of Wheat	3,609	4,653	28.9	7,020	94.5	8,750	142.5
Acres of Hay	5,480	5,297	-3.3	6,506	18.7	6,573	20.0
Acres of non-cropland	6,071	4,626	-23.8	2,001	-67.0	634	-89.6
Acres of CRP land	5,136	2,863	-44.3	2,142	-58.3	1,400	-72.7
<i>Cropping Systems (1000 acres)</i>							
Continuous corn	3,275	4,648	41.9	6,052	84.8	7,509	129.3
Continuous soybeans	2,839	2,491	-12.3	2,003	-29.4	1,735	-38.9
Continuous wheat	12	39	215.3	156	1154.0	289	2231.5
Corn-soybeans	30,647	32,704	6.7	32,636	6.5	33,669	9.9
Corn-Corn-Soybeans	11,046	13,151	19.1	14,646	32.6	16,349	48.0
Corn-Soybeans-Wheat	4,774	6,222	30.3	8,798	84.3	10,697	124.1
Soybeans-Soybeans-Corn	9,963	9,617	-3.5	8,639	-13.3	8,204	-17.7
Wheat-Soybeans	744	875	17.7	1,397	87.8	1,692	127.4
Corn-Corn-Alfalfa	1,609	1,870	16.2	2,340	45.4	2,642	64.2
<i>Environmental Quality</i>							
Nitrogen Runoff (1000s lbs.)	371,300	405,100	9.1	432,300	16.4	469,000	26.3
Nitrogen Percolation (1000s lbs)	637,500	698,000	9.5	762,800	19.7	841,800	32.0
Loss of Soil Organic Carbon (1000s metric tons)	925,800	932,100	0.7	941,700	1.7	948,800	2.5
Wind Erosion (1000s tons)	5,400	6,100	13.0	6,600	22.7	7,300	36.0
Water Erosion (1000s tons)	294,100	290,400	-1.3	285,300	-3.0	281,000	-4.4

Table 7. The Estimated Impacts of Higher Commodity Prices on Land Use and Environmental Quality in the Lake States

Land Use/Environmental Impacts	Baseline	Scenario 1: \$4 Corn		Scenario 2: \$6 Corn		Scenario 3: \$8 Corn	
		level	% change	level	% change	level	% change
<i>Land Use (1000 acres)</i>							
Acres of Corn	12,915	13,467	4.4	20,506	58.8	23,267	80.2
Acres of Soybeans	7,469	5,810	-22.2	3,535	-52.7	1,865	-75.0
Acres of Wheat	2,867	2,108	-26.5	1,492	-48.0	587	-79.5
Acres of Hay	6,986	7,051	0.9	7,087	1.5	9,102	30.3
Acres of non-cropland	2,140	2,104	-1.7	1,978	-7.6	1,843	-13.9
Acres of CRP land	2,730	2,282	-16.4	1,718	-37.1	1,601	-41.4
<i>Cropping Systems (1000 acres)</i>							
Continuous corn	2,197	2,597	18.2	7,836	256.7	11,515	424.1
Continuous soybeans	434	222	-48.9	34	-92.1	7	-98.3
Continuous wheat	82	51	-38.2	32	-60.9	-	-100.0
Corn-soybeans	3,612	2,883	-20.2	1,980	-45.2	1,140	-68.4
Corn-Corn-Soybeans	2,863	2,765	-3.4	3,274	14.4	2,167	-24.3
Corn-Soybeans-Wheat	1,214	804	-33.8	543	-55.2	197	-83.8
Soybeans-Soybeans-Corn	1,285	898	-30.1	318	-75.2	87	-93.2
Wheat-Soybeans	765	413	-46.0	166	-78.3	33	-95.7
Corn-Corn-Alfalfa	1,652	1,698	2.8	2,920	76.8	3,704	124.2
<i>Environmental Quality</i>							
Nitrogen Runoff (1000s lbs.)	53,600	46,000	-14.3	48,800	-9.0	49,400	-7.8
Nitrogen Percolation (1000s lbs)	31,400	114,800	-12.6	147,400	12.2	168,100	28.0
Loss of Soil Organic Carbon (1000s metric tons)	261,500	262,000	0.2	278,600	6.5	289,000	10.5
Wind Erosion (1000s tons)	2,700	2,700	-1.4	3,300	22.3	3,700	34.8
Water Erosion (1000s tons)	44,100	44,500	0.9	43,600	-1.1	43,200	-2.0

Table 8. The Estimated Impacts of Higher Commodity Prices on Land Use and Environmental Quality in the Northern Plains

Land Use/Environmental Impacts	Baseline	Scenario 1: \$4 Corn		Scenario 2: \$6 Corn		Scenario 3: \$8 Corn	
		level	% change	level	% change	level	% change
<i>Land Use (1000 acres)</i>							
Acres of Corn	8,292	5,794	-30.1	10,332	24.6	19,957	140.7
Acres of Soybeans	8,632	7,156	-17.1	7,869	-8.8	9,987	15.7
Acres of Wheat	46,957	55,462	18.1	44,039	-6.2	24,144	-48.6
Acres of Hay	12,687	19,682	55.1	16,316	28.6	10,723	-15.5
Acres of Sorghum	5,654	7,851	38.9	19,360	242.4	43,795	674.5
Acres of non-cropland	50,334	43,649	-13.3	33,056	-34.3	7,872	-84.4
Acres of CRP land	8,884	3,300	-62.9	1,458	-83.6	3,513	-60.5
<i>Cropping Systems (1000 acres)</i>							
Continuous corn	323	104	-67.7	562	74.1	2,542	687.2
Continuous soybeans	472	333	-29.4	259	-45.2	243	-48.5
Continuous wheat	14,444	17,382	20.3	8,819	-39.0	1,521	-89.5
Continuous sorghum	759	1,192	57.1	6,512	758.1	22,230	2829.2
Corn-soybeans	1,164	553	-52.5	1,013	-13.0	1,890	62.3
Corn-Corn-Soybeans	1,539	692	-55.0	1,753	13.9	4,727	207.2
Corn-Soybeans-Wheat	2,592	1,651	-36.3	1,953	-24.7	1,499	-42.2
Soybeans-Soybeans-Corn	1,380	770	-44.2	1,123	-18.6	1,601	15.9
Wheat-Soybeans	1,171	1,083	-7.5	672	-42.6	199	-83.0
Wheat-sorghum	916	1,261	37.6	1,411	53.9	767	-16.3
Corn-Corn-Alfalfa	1,194	1,015	-15.0	1,790	50.0	2,063	72.8
<i>Environmental Quality</i>							
Nitrogen Runoff (1000s lbs.)	25,900	18,200	-29.8	27,000	4.4	51,700	99.5
Nitrogen Percolation (1000s lbs)	30,000	25,400	-15.3	48,600	62.3	107,100	257.4
Loss of Soil Organic Carbon (1000s metric tons)	378,900	385,800	1.8	353,900	-6.6	325,200	-14.2
Wind Erosion (1000s tons)	73,200	152,200	-12.1	223,800	29.2	313,900	81.2
Water Erosion (1000s tons)	238,000	235,200	-1.2	246,000	3.4	255,900	7.5

Table 9. Effects of Mitigation Policies on Environmental Quality Measures

	Baseline	No Mitigation (\$6 Corn)	Adoption of No-Till Practices	Reducing N Application by 10%	Highly Erodable Land Not Converted
	level	level	% change	level	% change
<i>Corn Belt</i>					
Nitrogen Runoff (1000s lbs.)	371,300	432,300	16.4	377,400	1.6
Nitrogen Percolation (1000s lbs)	637,500	762,800	19.7	885,600	38.9
Loss of Soil Organic Carbon (1000s metric tons)	925,800	941,700	1.7	865,800	-6.5
Wind Erosion (1000s tons)	5,400	6,600	22.7	1,300	-76.4
Water Erosion (1000s tons)	294,100	285,300	-3.0	115,100	-60.9
<i>Great Lakes</i>					
Nitrogen Runoff (1000s lbs.)	53,600	48,800	-9.0	42,800	-20.1
Nitrogen Percolation (1000s lbs)	131,400	147,400	12.2	162,700	23.9
Loss of Soil Organic Carbon (1000s metric tons)	261,500	278,600	6.5	259,300	-0.9
Wind Erosion (1000s tons)	2,700	3,300	22.3	900	-65.7
Water Erosion (1000s tons)	44,100	3,600	-1.1	22,400	-49.3
<i>Northern Plains</i>					
Nitrogen Runoff (1000s lbs.)	25,900	27,000	4.4	24,000	-7.4
Nitrogen Percolation (1000s lbs)	30,000	48,600	62.3	54,600	82.3
Loss of Soil Organic Carbon (1000s metric tons)	378,900	353,900	-6.6	307,200	-18.9
Wind Erosion (1000s tons)	173,200	223,800	29.2	58,000	-66.5
Water Erosion (1000s tons)	238,000	246,000	3.4	136,400	-42.7

**Appendix
(For Review Only)**

Table A1. Coefficients Estimates of the Multinomial Logit Crop Choice Model for the Corn Belt

Variables	Corn		Soybeans		Wheat		Hay	
	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
Constant	1.9578	0.80	-6.4154	-2.59	0.8965	0.27	10.4755	2.94
<i>Price and Policy Variables</i>								
Expected price for corn	97.8664	2.13	46.6021	1.00	174.6190	2.90	125.3750	1.86
Expected price for soybeans	-12.0874	-1.08	5.9955	0.53	-46.2235	-2.95	-18.6335	-1.13
Expected price for wheat	19.7824	1.76	6.3283	0.56	30.3940	2.04	2.7748	0.17
Expected price for hay	-0.6213	-1.90	-0.3840	-1.16	0.0020	0.00	-0.5960	-1.34
ARP rate for wheat	0.0335	2.02	0.0230	1.37	0.0525	2.45	0.0362	1.49
Fuel price	0.2545	1.45	0.1552	0.87	0.6978	3.01	-0.0139	-0.06
Chemical price	-1.4391	-1.93	-0.7842	-1.04	-2.6534	-2.63	-1.8148	-1.67
Wage rates	-42.5986	-1.44	5.7895	0.19	-68.1538	-1.73	-33.9147	-0.82
Seeds prices	-0.4970	-2.54	-0.5210	-2.62	-0.9747	-3.86	-0.6237	-2.22
<i>Expected Yield and Yield Variation of Corn</i>								
Expected yield of corn	0.0129	5.95	0.0058	2.67	-0.0007	-0.25	-0.0041	-1.38
Expected variation of corn yield	0.0002	0.91	0.0007	3.92	-0.0007	-2.65	0.0003	1.08
<i>Land Characteristics</i>								
Good land	0.0868	1.77	0.1691	3.40	0.1521	2.38	0.0709	0.99
Bad land	-0.2867	-2.66	-0.6662	-5.38	-0.1242	-0.75	-0.2858	-2.05
Slope	-0.0054	-8.32	-0.0105	-14.90	-0.0025	-2.58	0.0007	0.82
Available water capacity	3.9808	5.30	0.3557	0.47	-3.8863	-4.03	0.1458	0.13
Organic matter	0.0001	0.01	-0.0028	-0.31	0.0062	0.40	-0.0249	-1.18
Soil pH	0.1085	2.69	0.1082	2.67	0.0939	1.82	-0.1370	-2.27

Coarse-textured soil	0.0863	1.74	0.3426	6.86	-0.0455	-0.64	-0.0743	-0.97
Fine-textured soil	0.1491	1.58	0.1314	1.40	-0.1597	-1.39	-0.1056	-0.70
<i>Weather Conditions during the Corn or Wheat Growing Season</i>								
Mean maximum temperature_corn	-0.0172	-1.53	0.0633	5.52	0.0419	2.71	-0.0565	-3.54
Mean precipitation_corn	-2.1576	-0.69	-5.6969	-1.79	-13.1349	-3.13	2.1552	0.46
St. deviation of precipitation_corn	-0.2706	-0.20	3.6804	2.72	6.0213	3.35	-1.9342	-0.96
Mean of precipitation_wheat	-0.2182	-0.31	-1.4967	-2.02	-0.3426	-0.35	-3.0090	-2.83
St. deviation of precipitation_wheat	-0.5315	-0.61	0.6219	0.71	-1.0238	-0.85	3.1182	2.58
<i>Cropping History</i>								
Previous year's crop is corn	4.6297	31.81	5.4578	37.37	3.6106	19.03	1.6536	7.02
Previous year's crop is soybeans	5.3835	31.78	4.6893	27.26	5.6368	29.20	1.6762	5.48
Previous year's crop is wheat	5.3360	24.38	3.6416	15.71	3.1194	10.98	4.6905	19.96
Previous year's crop is hay	4.2625	27.88	2.6644	14.23	2.3353	7.70	5.4887	36.45
<i>Interactions between Cropping History Dummy and State Dummy Variables</i>								
IA*corn	-1.0282	-6.51	-1.1562	-7.26	-2.5721	-7.18	-0.8981	-3.40
IA*soybeans	-0.3413	-1.77	-2.0615	-10.19	-3.6847	-9.98	-0.8963	-2.43
IA*wheat	-2.3198	-3.79	-1.4051	-2.02	1.9457	2.85	-3.2741	-3.64
IL*corn	-0.1008	-0.59	-0.3527	-2.06	-0.1989	-0.88	-0.0848	-0.29
IL*soybeans	0.1415	0.70	-1.0453	-5.05	-0.4090	-1.85	-0.1920	-0.50
IL*wheat	-0.5533	-1.95	-0.1492	-0.50	0.1479	0.41	-1.3813	-4.18
IL*hay	0.3227	0.95	0.7871	2.09	1.2585	2.49	0.7273	2.16
MO*corn	-0.4805	-2.39	-1.1709	-5.93	-0.0191	-0.08	-1.3265	-2.70
MO*soybeans	-2.1150	-11.35	-1.7912	-9.56	-2.5179	-11.91	-1.2338	-3.36
MO*wheat	-2.5150	-9.96	-0.9316	-3.63	-0.2471	-0.80	-2.6899	-8.94
MO*hay	-0.8709	-2.46	0.3140	0.89	0.7339	1.66	1.2370	4.09
IN*corn	0.4221	2.36	-0.3811	-2.15	0.0004	0.00	-0.5451	-1.57
IN*soybeans	-0.0848	-0.41	-0.9082	-4.31	-0.8261	-3.80	-0.5675	-1.34

IN*wheat	-0.8312	-2.88	-0.1818	-0.59	0.0650	0.17	-1.4511	-4.42
IN*hay	-0.0641	-0.17	0.2611	0.60	0.7558	1.35	0.7078	1.96
<i>Dummy Variables for Major Land Resource Areas</i>								
MLRA100	-1.2701	-3.02	-0.1579	-0.38	0.2470	0.47	-1.9449	-2.99
MLRA103	-0.5667	-5.30	0.3479	3.24	-1.3936	-1.89	-0.4505	-2.38
MLRA105	0.3743	3.30	-1.4637	-8.95	-0.3922	-0.74	0.3416	2.36
MLRA107	0.1275	1.42	0.5440	5.98	1.0451	5.52	0.0050	0.04
MLRA109	-0.3115	-2.90	0.1245	1.16	0.8978	4.62	-0.2506	-1.67
MLRA110	-0.3758	-2.64	0.0380	0.26	-0.8686	-3.02	-0.7245	-2.87
MLRA111	-0.2749	-2.55	0.1644	1.49	1.3352	7.94	-0.2957	-1.98
MLRA112	-0.6977	-4.07	-0.2504	-1.63	2.0612	10.00	-0.9772	-4.21
MLRA113	-0.1486	-1.24	0.6330	5.41	2.1703	12.75	-1.0368	-5.55
MLRA114	-0.2004	-1.68	0.1758	1.45	1.1772	6.68	-0.5169	-3.15
MLRA115	-0.1381	-1.46	0.3228	3.37	1.6365	10.91	-0.6401	-4.48
MLRA116B	-1.4966	-5.30	-0.4093	-1.96	1.4145	5.49	-0.7651	-2.91
MLRA120	-0.1416	-0.60	-0.3467	-1.36	1.0978	3.32	-0.3699	-1.17
MLRA121	-0.0433	-0.16	-0.6610	-2.14	1.1253	3.00	0.1933	0.62
MLRA122	0.4130	1.42	-0.6888	-2.01	1.6681	4.19	-0.1606	-0.41
MLRA124	-0.2515	-1.03	-1.9706	-5.90	1.1079	3.18	-0.0800	-0.30
MLRA126	-1.1875	-2.13	-2.2007	-2.77	-0.6675	-0.58	0.4415	0.97
MLRA131	-1.1048	-6.51	-0.3665	-2.32	1.4175	6.32	-3.2054	-5.69
MLRA134	-0.1606	-0.49	0.0559	0.17	2.1977	5.90	-1.9020	-2.31
MLRA139	-0.3893	-2.11	-0.4219	-2.13	0.8862	3.41	-0.2308	-1.05
MLRA95B	0.0997	0.59	-0.4165	-2.34	-1.8311	-3.00	0.0785	0.34
MLRA98	-0.2540	-1.14	-0.3011	-1.31	-0.9208	-1.91	-0.3985	-1.16
MLRA99	-0.4297	-2.32	0.3782	2.03	1.9471	8.39	-0.4078	-1.66

Model Performance Measures

Percent of correct prediction	66%
Percent of actual choices predicted as the 1st or 2nd choice	92%
Log of likelihood function	-46033

Table A2. Estimates of the Marginal Effects on the Probabilities to Choose Alternative Crops in the Corn Belt

	Corn	Soybeans	Wheat	Hay	Other
Constant	0.9072	-1.3374	0.0891	0.3349	0.0062
Price and Policy Variables					
Expected price for corn	5.8951	-7.6684	4.9792	1.7949	-5.0007
Expected price for soybeans	-1.4797	3.2734	-1.9733	-0.3509	0.5305
Expected price for wheat	2.0171	-1.8219	0.8667	-0.3146	-0.7473
Expected price for hay	-0.0558	0.0143	0.0219	-0.0065	0.0260
ARP rate for wheat	0.0015	-0.0013	0.0013	0.0004	-0.0018
Seeds prices	0.0049	-0.0053	-0.0246	-0.0068	0.0317
Fuel price	0.0111	-0.0165	0.0244	-0.0066	-0.0124
Fertilizer price	-0.0737	0.0982	-0.0756	-0.0247	0.0758
Wage rates	-6.1018	7.2584	-2.2779	-0.3116	1.4329
Expected Yield and Yield Variation of Corn					
Expected yield of corn	0.0017	-0.0005	-0.0004	-0.0004	-0.0004
Expected variation of corn yield	0.0000	0.0001	0.0000	0.0000	0.0000
Land Characteristics					
Good land	-0.0089	0.0140	0.0022	-0.0005	-0.0068
Bad land	0.0342	-0.0696	0.0126	-0.0001	0.0230
Slope	0.0003	-0.0010	0.0002	0.0002	0.0003
Available water capacity	0.7486	-0.3404	-0.2810	-0.0533	-0.0739
Organic matter	0.0006	-0.0004	0.0004	-0.0008	0.0002
Soil pH	0.0066	0.0040	0.0003	-0.0068	-0.0041
Coarse-textured soil	-0.0224	0.0462	-0.0099	-0.0057	-0.0082
Fine-textured soil	0.0164	0.0071	-0.0130	-0.0062	-0.0043
Weather Conditions during Corn and Wheat Growing Season					
Mean max temperature_corn	-0.0105	0.0118	0.0014	-0.0020	-0.0007
Mean precipitation_corn	0.5490	-0.4520	-0.4763	0.1591	0.2202

St. deviation of precipitation_corn	-0.5836	0.5311	0.2306	-0.0894	-0.0886
Mean of precipitation_wheat	0.1905	-0.1902	0.0196	-0.0807	0.0608
St. deviation of precipitation_wheat	-0.1915	0.1597	-0.0521	0.1036	-0.0197
Cropping History					
Previous year's crop is corn	0.0742	0.2652	-0.0320	-0.0610	-0.2465
Previous year's crop is soybeans	0.2499	0.0195	0.0593	-0.0708	-0.2580
Previous year's crop is wheat	0.3739	-0.1188	-0.0456	0.0350	-0.2445
Previous year's crop is hay	0.3034	-0.1423	-0.0426	0.0841	-0.2027
Interactions between Cropping History Dummies and State Dummy Variables					
IA*corn	0.0259	-0.0164	-0.0764	-0.0004	0.0672
IA*soybeans	0.2780	-0.2225	-0.1292	-0.0035	0.0772
IA*wheat	-0.2397	0.0314	0.1746	-0.0605	0.0941
IL*corn	0.0291	-0.0409	-0.0009	0.0015	0.0113
IL*soybeans	0.1589	-0.1760	-0.0043	-0.0010	0.0224
IL*wheat	-0.0621	0.0465	0.0246	-0.0338	0.0249
IL*hay	-0.0748	0.0627	0.0373	0.0106	-0.0358
MO*corn	0.0725	-0.1234	0.0324	-0.0266	0.0451
MO*soybeans	-0.0881	0.0093	-0.0375	0.0100	0.1063
MO*wheat	-0.2880	0.1640	0.0666	-0.0384	0.0959
MO*hay	-0.2265	0.1314	0.0471	0.0491	-0.0011
IN*corn	0.1274	-0.1069	-0.0022	-0.0213	0.0029
IN*soybeans	0.1185	-0.1182	-0.0205	-0.0093	0.0296
IN*wheat	-0.1044	0.0754	0.0277	-0.0313	0.0326
IN*hay	-0.0701	0.0320	0.0314	0.0202	-0.0136
Dummy Variables for Major Land Resource Areas					
MLRA100	-0.1812	0.1303	0.0468	-0.0403	0.0444
MLRA103	-0.1015	0.1483	-0.0579	-0.0050	0.0161
MLRA105	0.2400	-0.2738	-0.0027	0.0146	0.0219
MLRA107	-0.0648	0.0546	0.0371	-0.0070	-0.0198

MLRA109	-0.0862	0.0424	0.0478	-0.0053	0.0012
MLRA110	-0.0395	0.0691	-0.0318	-0.0155	0.0176
MLRA111	-0.0937	0.0374	0.0670	-0.0082	-0.0024
MLRA112	-0.1261	0.0118	0.1192	-0.0216	0.0167
MLRA113	-0.1334	0.0882	0.0967	-0.0377	-0.0138
MLRA114	-0.0748	0.0346	0.0580	-0.0161	-0.0017
MLRA115	-0.0895	0.0439	0.0759	-0.0226	-0.0077
MLRA116B	-0.2372	0.0889	0.1094	-0.0003	0.0392
MLRA120	-0.0041	-0.0556	0.0616	-0.0091	0.0072
MLRA121	0.0404	-0.1214	0.0650	0.0089	0.0071
MLRA122	0.1173	-0.1861	0.0812	-0.0101	-0.0024
MLRA124	0.1606	-0.3054	0.0918	0.0118	0.0411
MLRA126	0.0546	-0.2063	0.0326	0.0472	0.0719
MLRA131	-0.1348	0.0654	0.1040	-0.0830	0.0485
MLRA134	-0.0555	0.0019	0.1096	-0.0610	0.0050
MLRA139	-0.0364	-0.0361	0.0583	0.0000	0.0142
MLRA95B	0.1068	-0.0476	-0.0817	0.0066	0.0158
MLRA98	0.0175	-0.0006	-0.0318	-0.0050	0.0198
MLRA99	-0.1582	0.0799	0.0959	-0.0117	-0.0060

Table A3. Coefficient Estimates of the Multinomial Logit Crop Choice Model for the Lake States

Variables	Corn		Soybeans		Wheat		Hay	
	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
Constant	-4.2097	-2.00	-6.1975	-2.25	-0.9407	-0.30	0.9360	0.33
Price and Policy Variables								
Expected price for corn	178.8680	4.28	6.1364	0.10	115.3020	1.25	-36.7719	-0.70
Expected price for soybeans	-33.1545	-2.18	3.0706	0.14	-69.7778	-2.22	52.5357	2.71
Expected price for wheat	-19.1419	-1.40	-20.4366	-1.14	-6.5084	-0.29	-42.9820	-2.19
Expected price for hay	-0.1987	-0.48	-1.5388	-2.51	-0.4696	-0.59	0.7867	1.57
ARP rate for wheat	0.0201	2.92	0.0006	0.06	0.0143	1.01	0.0002	0.02
Fuel price	-0.4499	-2.61	-0.1011	-0.46	-0.0230	-0.08	-0.3508	-1.58
Chemical price	-1.0808	-2.84	-0.9035	-1.79	-1.6790	-2.44	-0.4028	-0.82
Wage rate	53.6066	2.08	-32.4369	-0.83	46.0995	0.82	-44.8472	-1.34
Expected Yield and Yield Variation of Corn								
Expected yield of corn	0.0112	5.05	0.0371	12.25	-0.0061	-1.96	-0.0082	-2.99
Expected variation of corn yield	0.0003	1.25	0.0021	6.57	-0.0007	-1.58	0.0006	1.63
Land Characteristics								
Good land	0.2417	4.10	0.1396	1.86	0.3515	3.55	0.0467	0.63
Bad land	0.0427	0.35	-0.4760	-2.11	-0.4523	-1.72	-0.0153	-0.11
Slope	-0.0029	-3.66	-0.0079	-6.63	0.0007	0.41	-0.0023	-2.57
Available water capacity	2.3504	2.99	3.0675	3.08	1.3733	0.96	2.7882	2.76
Organic matter	-0.0120	-2.87	-0.0229	-3.56	-0.0032	-0.40	-0.0132	-2.59
Soil pH	0.0548	1.08	0.1651	2.42	0.3216	3.13	-0.0637	-1.02
Coarse-textured soil	0.0032	0.04	0.0199	0.25	0.3181	3.19	0.0380	0.35
Fine-textured soil	0.0183	0.24	-0.3617	-3.62	0.0139	0.12	-0.1023	-1.05
Weather Conditions during the Corn Growing Season								
Mean maximum temperature	0.0340	3.10	0.0176	1.26	0.0490	2.92	0.0114	0.84
Mean precipitation	1.4843	0.28	-0.3686	-0.05	-37.1972	-4.07	10.1975	1.55

St. deviation of precipitation	1.7253	0.92	-0.6437	-0.28	5.5818	1.80	-3.0008	-1.23
Cropping History								
Previous year's crop is corn	3.9595	34.79	4.0513	21.93	1.7389	10.01	1.1112	4.95
Previous year's crop is soybeans	3.8510	21.35	4.0621	17.35	3.4717	16.39	0.3953	0.64
Previous year's crop is wheat	2.6960	15.46	2.9970	12.47	1.3989	5.29	1.8173	6.05
Previous year's crop is hay	3.5208	11.17	2.9193	6.28	2.1679	5.06	6.9353	21.98
Interactions between cropping history dummy and state dummy variables								
MN*Corn	-1.3329	-9.48	-0.5768	-2.73	-0.2974	-1.29	-1.7099	-6.38
MN*Soybeans	-0.2037	-0.97	-1.7989	-6.74	-1.1204	-4.31	-1.5186	-2.22
MN*Wheat	-0.7599	-3.30	-0.4366	-1.52	-0.6272	-2.14	-2.2125	-5.41
MN*Hay	-0.0346	-0.10	-0.8045	-1.51	-1.3764	-2.50	-2.5364	-7.09
WI*Corn	-1.2644	-9.02	-1.6601	-6.39	-1.3310	-4.02	-1.6168	-6.45
WI*Soybeans	-0.4816	-1.32	-0.0248	-0.06	-1.2830	-2.32	-1.0132	-1.13
WI*Wheat	-1.3714	-3.42	-0.0676	-0.14	0.9802	1.94	-1.8507	-3.46
WI*Hay	0.0649	0.19	-1.4499	-2.16	-0.9042	-1.48	-2.9536	-8.63
Dummy Variables for Major Land Resource Areas								
MLRA561	-1.4218	-5.40	2.3775	2.30	1.9658	5.34	-1.6584	-5.39
MLRA571	-0.5228	-1.71	1.9073	1.73	1.7311	4.36	-0.5007	-1.59
MLRA881	-0.8099	-2.05	1.8885	1.50	1.5746	3.69	-0.2901	-0.89
MLRA901	0.6368	2.92	1.8785	1.81	-2.2990	-2.15	1.0036	4.33
MLRA911	0.5064	2.30	2.3033	2.22	0.0877	0.18	0.4999	2.11
MLRA971	0.2063	0.91	1.9599	1.91	0.2179	0.53	-0.8489	-2.92
MLRA981	0.4595	2.15	2.4282	2.37	1.1474	3.21	-0.7526	-2.87
MLRA991	-0.0236	-0.11	2.1906	2.14	0.6344	1.71	-1.7369	-5.57
MLRA1031	0.4677	1.96	2.7085	2.61	0.8010	1.88	0.4358	1.61
MLRA1041	0.5329	2.06	2.4988	2.40	-0.2680	-0.44	0.2021	0.64
MLRA1051	0.6400	2.84	0.7776	0.75	-1.3467	-1.94	1.1375	4.67
MLRA1101	0.9192	3.05	3.0987	2.93	1.7007	3.37	0.2422	0.54
MLRA1111	0.5109	1.92	2.5911	2.50	1.1437	2.71	-1.1529	-2.97

MLRA94A1	0.4736	1.83	2.9294	2.77	0.0621	0.13	-0.2119	-0.74
MLRA95A1	0.9696	4.57	1.6171	1.52	-0.2500	-0.52	1.3498	6.14
MLRA95B1	0.8775	4.12	1.7726	1.71	0.7733	1.91	1.2689	5.60
MLRA1021	0.1791	0.75	2.6760	2.58	1.9493	4.89	-0.1257	-0.44
MLRA1021	0.5635	1.99	2.8075	2.68	-1.9838	-1.81	0.6928	2.02

Model Performance Measures

Percent of correct prediction 66%

Percent of actual choices predicted as the 1st or 2nd choice 90%

Log of likelihood function -20051

Table A4. Estimates of the Marginal Effects on the Probabilities to Choose Alternative Crops in the Lake States

	corn	soybeans	wheat	hay	other
Constant	-0.3212	-0.3121	0.0689	0.2521	0.3123
Price and Policy Variables					
Expected price for corn	29.7314	-12.1691	2.0807	-9.6169	-10.0261
Expected price for soybeans	-6.8049	2.8340	-2.5127	5.0040	1.4795
Expected price for wheat	-0.1546	-0.4556	0.2823	-2.1018	2.4296
Expected price for hay	0.0470	-0.1351	-0.0066	0.0688	0.0259
ARP rate for wheat	0.0032	-0.0014	0.0003	-0.0008	-0.0012
Fuel price	-0.0562	0.0222	0.0074	-0.0064	0.0329
Chemical price	-0.0828	-0.0002	-0.0447	0.0216	0.1061
Wage rate	12.3313	-6.9035	1.4384	-5.0739	-1.7923
Expected Yield and Yield Variation of Corn					
Expected yield of corn	-0.0002	0.0029	-0.0007	-0.0011	-0.0009
Expected variation of corn yield	-0.0001	0.0002	-0.0001	0.0000	-0.0001
Land Characteristics					
Good land	0.0247	-0.0056	0.0096	-0.0075	-0.0212
Bad land	0.0467	-0.0454	-0.0155	0.0005	0.0138
Slope	0.0001	-0.0006	0.0001	0.0000	0.0003
Available water capacity	0.0673	0.1160	-0.0091	0.0845	-0.2587
Organic matter	0.0000	-0.0013	0.0003	-0.0003	0.0014
Soil pH	-0.0042	0.0101	0.0113	-0.0079	-0.0092
Coarse-textured soil	-0.0070	-0.0008	0.0127	0.0016	-0.0065
Fine-textured soil	0.0312	-0.0359	0.0033	-0.0062	0.0076
Weather Conditions					
Mean max temperature_corn	0.0034	-0.0010	0.0013	-0.0007	-0.0031
Mean precipitation_corn	0.4484	0.1012	-1.5671	0.7339	0.2837
St. deviation of precipitation_corn	0.3676	-0.2078	0.2149	-0.2815	-0.0932

Cropping History					
Previous year's crop is corn	0.3335	0.1070	-0.0215	-0.0960	-0.3229
Previous year's crop is soybeans	0.3154	0.1053	0.0528	-0.1451	-0.3284
Previous year's crop is wheat	0.1675	0.0898	-0.0103	0.0054	-0.2524
Previous year's crop is hay	0.1073	-0.0005	-0.0035	0.3215	-0.4248
Interactions between cropping history dummy and state dummy variables					
MN*Corn	-0.1189	0.0435	0.0165	-0.0628	0.1217
MN*Soybeans	0.1610	-0.1453	-0.0255	-0.0855	0.0952
MN*Wheat	-0.0066	0.0230	-0.0054	-0.1186	0.1076
MN*Hay	0.1653	-0.0544	-0.0434	-0.1648	0.0973
WI*Corn	-0.0222	-0.0584	-0.0190	-0.0519	0.1515
WI*Soybeans	-0.0226	0.0439	-0.0425	-0.0475	0.0687
WI*Wheat	-0.1735	0.0863	0.0658	-0.0763	0.0977
WI*Hay	0.2345	-0.1253	-0.0197	-0.1955	0.1060
Dummy Variables for Major Land Resource Areas					
MLRA56	-0.3689	0.3177	0.0881	-0.0740	0.0372
MLRA57	-0.2245	0.2086	0.0656	-0.0266	-0.0230
MLRA88	-0.2778	0.2264	0.0631	-0.0009	-0.0108
MLRA90	-0.0217	0.1517	-0.1203	0.0421	-0.0519
MLRA91	-0.0892	0.1857	-0.0226	0.0050	-0.0789
MLRA97	-0.0679	0.1774	-0.0068	-0.0745	-0.0282
MLRA98	-0.0739	0.1982	0.0237	-0.0819	-0.0661
MLRA99	-0.0951	0.2158	0.0142	-0.1283	-0.0065
MLRA103	-0.1313	0.2223	0.0043	-0.0014	-0.0939
MLRA104	-0.0812	0.2067	-0.0382	-0.0163	-0.0710
MLRA105	0.0337	0.0374	-0.0734	0.0534	-0.0510
MLRA110	-0.0868	0.2237	0.0319	-0.0357	-0.1331
MLRA111	-0.0609	0.2122	0.0226	-0.1118	-0.0621
MLRA94A	-0.1095	0.2516	-0.0261	-0.0449	-0.0711

MLRA95A	0.0088	0.0871	-0.0403	0.0490	-0.1046
MLRA95B	-0.0297	0.1010	0.0020	0.0438	-0.1171
MLRA102A	-0.1742	0.2324	0.0573	-0.0315	-0.0839
MLRA102B	-0.0897	0.2453	-0.1125	0.0190	-0.0622

Table A5. Coefficient Estimates of the Multinomial Logit Crop Choice Model for the Northern Plains

Variables	Corn		Soybeans		Wheat		Hay		Sorghum	
	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
Constant	11.9919	3.00	2.9508	0.62	-7.3488	-2.91	-9.0456	-1.09	-10.4410	-1.81
Price and Policy Variables										
Expected price for corn	24.7808	1.28	-68.8251	-3.07	8.1948	0.60	-0.5339	-0.01	80.4844	3.53
Expected price for soybeans	-2.1867	-0.15	11.1117	0.63	-42.4498	-4.40	-40.4845	-1.29	-52.4995	-2.58
Expected price for wheat	3.9803	0.31	12.8079	0.84	15.3211	1.82	29.0876	1.06	45.2392	3.37
Expected price for hay	-1.4591	-4.32	-0.7687	-1.95	0.7300	3.35	1.4036	1.99	0.2304	0.57
Expected price for Sorghum	97.0073	2.02	54.2836	0.94	-34.6462	-1.14	-90.5606	-0.92	71.1025	0.88
ARP rate for wheat	0.0252	1.94	0.0105	0.69	-0.0078	-0.98	-0.0212	-0.81	0.0281	1.38
Fuel price	-0.4785	-1.03	0.2621	0.48	0.4454	1.54	1.0510	1.10	0.0605	0.09
Chemical price	-1.4612	-1.51	0.0263	0.02	-0.2073	-0.34	2.0988	1.06	-0.5036	-0.34
Wage rate	-15.6491	-0.62	15.3320	0.51	8.1991	0.47	-10.0534	-0.19	40.2058	1.24
Expected Yield and Yield Variation of Corn										
Expected yield of corn	0.0158	17.48	0.0092	7.84	-0.0059	-9.96	-0.0035	-1.92	0.0013	1.39
Expected variation of corn yield	-0.0011	-7.71	0.0008	5.96	-0.0002	-4.19	-0.0010	-4.09	-0.0006	-6.47
Land Characteristics										
Good land	0.3158	6.51	0.0409	0.71	0.1802	5.60	0.0534	0.52	-0.0105	-0.21
Bad land	-0.2326	-2.54	-0.3341	-2.91	-0.2664	-4.08	0.4792	3.07	0.1531	1.66
Slope	-0.0008	-1.04	-0.0042	-4.66	-0.0084	-12.88	-0.0027	-1.77	-0.0066	-6.83
Available water capacity	0.4530	0.58	8.7050	8.84	-0.4726	-0.77	-2.6342	-1.72	-0.9751	-1.06
Organic matter	-0.0892	-5.52	-0.0042	-0.22	-0.0060	-0.59	-0.0999	-2.92	0.0308	1.37
Soil pH	-0.2579	-5.62	-0.4392	-8.24	-0.0496	-1.35	-0.1483	-1.52	-0.2064	-4.12
Coarse-textured soil	0.0090	0.18	0.4652	8.60	-0.0147	-0.39	-0.0978	-0.91	0.2266	4.17
Fine-textured soil	0.3115	4.35	0.5594	6.32	-0.1913	-3.73	0.1774	1.24	0.2354	3.03
Weather Conditions										
Mean max temperature_corn	-0.1102	-12.21	-0.1556	-13.50	0.0896	13.49	-0.0380	-1.92	0.0773	6.59

Mean precipitation_corn	6.6992	1.60	3.0277	0.62	21.7246	7.66	28.2513	3.14	22.7493	5.08	
St. deviation of precipitation_corn	5.3836	3.23	15.9528	8.47	-8.9613	-7.96	-1.5999	-0.46	-2.2169	-1.18	
Mean of precipitation_wheat	49.4095	7.50	158.0720	20.27	-36.5730	-8.39	21.4508	1.64	14.2187	1.93	
St. deviation of precipitation_wheat	-18.6442	-8.15	-50.7841	-18.25	20.5450	13.48	-8.0472	-1.76	-4.2110	-1.57	
Mean of snow_wheat	-0.9805	-1.67	-0.1957	-0.30	0.5053	1.10	3.4182	2.82	-0.0150	-0.02	
St. deviation of snow_wheat	0.5570	2.40	-0.0186	-0.06	-0.4027	-2.09	-1.8166	-3.57	0.0942	0.32	
Cropping History											
Previous year's crop is corn	2.7421	53.27	3.1304	38.42	-0.7614	-12.83	0.7811	5.40	1.1276	12.37	
Previous year's crop is soybeans	3.5369	39.12	3.1104	28.21	0.9881	10.99	1.0782	4.65	3.1980	29.34	
Previous year's crop is sorghum	0.4681	5.63	2.2137	23.83	-0.4895	-8.69	-0.1497	-0.70	3.1902	43.81	
Previous year's crop is wheat	-0.2709	-4.58	0.9972	12.01	-0.2777	-9.74	-0.3918	-2.91	0.9940	14.60	
Previous year's crop is hay	1.9322	13.47	1.6509	7.57	-0.6124	-3.79	6.8877	51.58	1.4406	6.67	
State Dummies											
N. Dakota dummy	-1.3656	-7.97	-1.9160	-8.89	0.3349	2.69	-1.9464	-5.49	-3.9417	-9.72	
S. Dakota dummy	0.2916	1.78	-1.5070	-7.88	-0.8706	-7.52	-0.5639	-1.65	-0.9830	-5.09	
<i>Model Performance Measures</i>											
Percent of correct prediction					53%						
Percent of actual choices predicted as the 1st or 2nd choice					80%						
Log of likelihood function					-51382						

Table A6. Estimates of the Marginal Effects on the Probabilities to Choose Alternative Crops in the Northern Plains

	Corn	Soybeans	Wheat	Hay	Sorghum	Other
Constant	1.3038	0.1120	-1.2023	-0.1397	-0.6820	0.6082
Price and Policy Variables						
Expected price for corn	2.7120	-5.6834	-0.4494	-0.1475	5.7905	-2.2221
Expected price for soybeans	1.2406	1.8855	-5.5399	-0.3649	-2.5322	5.3108
Expected price for wheat	-0.9229	-0.0550	0.9631	0.2703	2.4864	-2.7419
Expected price for hay	-0.1345	-0.0252	0.1510	0.0239	0.0197	-0.0350
Expected price for Sorghum	7.5580	0.7418	-10.0970	-1.7194	4.2343	-0.7178
ARP rate for wheat	0.0019	-0.0001	-0.0026	-0.0004	0.0018	-0.0005
Fuel price	-0.0630	0.0192	0.0751	0.0149	-0.0064	-0.0399
Chemical price	-0.1271	0.0415	0.0035	0.0373	-0.0155	0.0603
Wage rate	-2.3465	0.7601	0.4690	-0.1889	2.5787	-1.2724
Expected Yield and Yield Variation of Corn						
Expected yield of corn	0.0013	0.0002	-0.0015	-0.0001	0.0000	0.0000
Expected variation of corn yield	-0.0001	0.0001	-.000003	-0.00001	0.0000	0.0001
Land Characteristics						
Good land	0.0228	-0.0073	0.0222	-0.0011	-0.0096	-0.0269
Bad land	-0.0103	-0.0134	-0.0402	0.0090	0.0233	0.0316
Slope	0.0003	-0.0001	-0.0011	.000009	-0.0002	0.0010
Available water capacity	-0.1347	0.5302	-0.1639	-0.0484	-0.1509	-0.0324
Organic matter	-0.0076	0.0017	0.0006	-0.0011	0.0035	0.0029
Soil pH	-0.0083	-0.0171	0.0092	-0.0001	-0.0050	0.0212
Coarse-textured soil	-0.0121	0.0255	-0.0142	-0.0023	0.0110	-0.0078
Fine-textured soil	0.0150	0.0257	-0.0524	0.0010	0.0114	-0.0007
Weather Conditions						
Mean max temperature_corn	-0.0087	-0.0086	0.0173	-0.0003	0.0060	-0.0055

Mean precipitation_corn	-0.3315	-0.5413	2.6818	0.2676	0.8434	-2.9200
St. deviation of precipitation_corn	0.3258	0.9679	-1.7337	-0.0296	-0.1479	0.6175
Mean of precipitation_wheat	1.1685	8.5711	-9.5931	0.0207	-0.3630	0.1959
St. deviation of precipitation_wheat	-0.8135	-2.8031	4.5854	-0.0452	-0.0587	-0.8649
Mean of snow_wheat	-0.1059	0.0006	0.0952	0.0515	-0.0056	-0.0358
St. deviation of snow_wheat	0.0643	-0.0077	-0.0742	-0.0269	0.0134	0.0312
Cropping History						
Previous year's crop is corn	0.1683	0.1187	-0.2588	-0.0022	0.0314	-0.0573
Previous year's crop is soybeans	0.1752	0.0534	-0.0442	-0.0101	0.1183	-0.2925
Previous year's crop is sorghum	-0.0365	0.0932	-0.2034	-0.0094	0.2035	-0.0475
Previous year's crop is wheat	-0.0513	0.0594	-0.0774	-0.0063	0.0686	0.0070
Previous year's crop is hay	0.1016	0.0359	-0.2280	0.0899	0.0662	-0.0656
State Dummies						
North Dakota	-0.0296	-0.0411	0.2215	-0.0162	-0.2413	0.1067
South Dakota	0.0941	-0.0745	-0.1023	-0.0027	-0.0309	0.1162
