Evaluation of Conservation Policies for Reducing Nitrogen Loads to the Mississippi River and Gulf of Mexico

by

Katsuya Tanaka[1]

and

JunJie Wu[2]

[1] Graduate School for International Development and Cooperation, Hiroshima University, Japan.
Phone: +81 82-424-6935, Fax: +81 82-424-6935, Email: katsuyat@hiroshima-u.ac.jp
[2] Department of Agricultural and Resource Economics, Oregon State University. Phone: 541-737-3060, Fax: 541-737-1441, Email: Junjie.Wu@oregonstate.edu

Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Denver, Colorado, August 1-4, 2004.

ABSTRACT

This study integrates economic and physical models to estimate the social costs of several commonly suggested policies (chemical-use tax and three types of conservation payments) for reducing nitrogen loads to the Mississippi River and for controlling hypoxia in the Gulf of Mexico. The economic models predict farmers' crop rotations, tillage practices, and participation in the Conservation Reserve Program (CRP) at more than 44,000 Natural Resource Inventory sites in the Upper Mississippi River Basin. The estimated land use changes under the four policies are incorporated into a physical model to assess their impact on nitrate-N concentrations in the Mississippi River. Results suggest that the fertilizer-use tax is much more cost-effective than the three conservation easement policies. Incentive payments for conservation tillage are most cost-effective among the three conservation easement policies, but can reduce nitrate-N concentrations only to a limited level. The potential for incentive payments for corn-soybean rotations is even more limited as an instrument for reducing nitrate-N concentrations in the Mississippi River. These payments also impose a higher cost to society than payments for conservation tillage. Payments for cropland retirement can be used to achieve the largest reduction in nitrate-N concentrations, but also impose the largest cost to society among the four policies considered in this paper. Results also suggest that, in contrast to previous studies, the targeted fertilizer-use tax reduces the aggregate farm profit loss under the uniform fertilizer-use tax by up to 30 percent.

Key words: chemical-use taxes, conservation easements, hypoxia, land use changes, nitrate water pollution, nonpoint source pollution, SWAT.

JEL codes: Q18, Q53, Q58 .

The productivity of U.S. agriculture has increased dramatically over the past 50 years, due largely to the adoption of new technologies and increased chemical use. As a consequence, agricultural runoff has been identified as a primary source of water quality problems in surveyed rivers and streams (U.S. Environmental Protection Agency 2002). NO_3-N in excessive amounts may cause eutrophication in salty waters, depleting the level of dissolved oxygen and harming aquatic ecosystems. When oxygen levels fall below the concentrations needed to sustain marine life, a condition known as hypoxia will occur. The Upper Mississippi River Basin (UMRB) is under increasing scrutiny as a major source of NO_3-N loadings to the Mississippi River, causing hypoxia in the Gulf of Mexico. Although the UMRB comprises only 15 percent of the drainage area of the entire MRB, it contributes more than half of NO_3-N discharged to the Gulf of Mexico (Goolsby and Battaglin).

Numerous federal and state incentive-based programs have been initiated with goals of reducing the environmental impact of agricultural production, including the Conservation Reserve Program (CRP), Environmental Quality Incentive Program (EQIP), and Wetland Reserve Program (WRP). The newly adopted Conservation Security Act expands these existing programs and includes provisions for new programs. *Ex ante* analysis of the likely cost effectiveness and environmental efficacy of changes in these programs, or *ex post* assessment of the outcomes of these programs, requires a large scale economic model capable of estimating the costs of alternative land uses on spatially heterogeneous land, combined with the capacity to estimate the environmental effects of these alternative land uses at the regional scale. It is also important to employ micro-level data in policy analysis both to achieve consistency with the underlying economic theory on which land use (discrete) choice models are based and to capture accurately the significant spatial variability in economic and environmental variables (Antle and Capalbo; Hochman and Zilberman; Wu at al.).

The primary objective of this paper is to develop an empirical framework to estimate the social costs of alternative conservation programs (payments for conservation tillage, corn-soybean rotation, and cropland retirement) and input-use taxes for reducing NO_3-N loads to surface waters within the UMRB and Gulf of Mexico. This objective is achieved by integrating a set of econometric models and a physical model (The Soil and Water Assessment Tool; SWAT). The econometric models are estimated to predict crop choice, crop rotations, tillage practices, and participation in the CRP at more than 44,000 Natural Resource Inventory (NRI) sites in the UMRB. Based on the predicted land use changes from the econometric models, SWAT then simulates the level of NO_3-N concentrations in the Mississippi River. This integrated framework allows region-scale policy simulations while incorporating site-specific economic behavior and physical characteristics. The primary data sources used in this analysis include the 1982, 1987, 1992, and 1997 National

Resource Inventories (NRI), the SOIL5 database, and price and cost data published by the U.S. Department of Agriculture.

Our empirical results show that a fertilizer-use tax is much more cost-effective than the three conservation easement policies for reducing NO_3-N concentrations in the Mississippi River. However, a fertilizer-use tax is much less feasible politically than the easement policies. Among the three easement policies considered in this study, the incentive payment for conservation tillage is most cost-effective, but it can only reduce nitrate-N concentrations by a limited level. The potential for the incentive payment for corn-soybean rotations is even more limited as an instrument for reducing NO_3-N concentrations. This payment also imposes a larger cost to society. The payment for cropland retirement can be used to achieve the largest reduction in NO_3-N concentrations, but it imposes the highest cost to society among the four policies considered in this paper. Results also suggest that, in contrast to previous studies, the targeted fertilizer-use tax reduces the aggregate farm profit loss under the uniform fertilizer-use tax by up to 30 percent.

Literature Review

Much research has focused on the impact of farming practices on nitrate water pollution at the field, farm, or watershed levels (e.g., De Roo; Pionke and Urban; Hallberg; Gilliam and Hoyt; Grady). These studies have linked nitrate water pollution to land use, nitrogen application rates, crop management practices, and hydrologic settings. These studies, however, have not examined how the decisions that led to those cropping patterns and farming practices were made. Thus, they cannot be used to assess the effectiveness of alternative policies for controlling agricultural pollution.

The design of policy to encourage adoption of environmentally-friendly farming practices requires analysis of adoption decisions. In response, many studies examine factors affecting adoption of specific management practices, such as conservation tillage (Ervin and Ervin; Korsching et al.; Williams, Llewelyn, and Barnaby; Helms, Bailey, and Glover; Kurkalova, Kling and Zhao; Yiridoe and Weersink), irrigation technologies (Caswell and Zilberman), and water quality protection practices (Fuglie and Bosch; Cooper and Keim). For example, Cooper and Keim use survey data to estimate payment levels that would be needed to induce farmers to adopt alternative water quality protection practices.

Other policy instruments proposed for controlling agricultural pollution include input taxes, input regulations, ambient taxes, random fines, direct revelation, and type-specific contracts (Griffin and Bromley; Shortle and Dunn; Segerson; Xepapadeas; Cabe and Herriges). Instruments that provide flexible incentives (such as ambient taxes) can be used to induce first-best control of nonpoint pollution (Segerson), but information about farm-level characteristics is needed to design these first-best policy instruments. They have thus been criticized for high information and/or transactions costs (e.g., Cabe and Herriges; Batie and Ervin). This has led some to suggest the use of second best policy instruments for controlling nonpoint pollution (Helfand and House; Wu and Babcock).

A number of empirical studies have modeled the interaction between agricultural production and water quality. These studies can be classified into disaggregate models and aggregate models. The disaggregated models are site-specific and model micro-unit decisions and their impact on water quality at the farm or watershed levels (e.g., Braden et al.; Johnson, Adams, and Perry; Taylor, Adams, and Miller). The aggregate models can be further classified into two groups. One group integrates an aggregate economic model (usually a regional or national linear programming model) with a physical model to analyze the impact agricultural practices and policies on water quality (e.g., Piper, Huang, and Ribaudo; Mapp et al.). The aggregate economic model predicts the impact of alternative policies on land allocation and input uses, and the physical model estimates the impact of crop production on water quality. The second group of aggregate models examines policy impacts at the regional or national level while incorporating site-specific land characteristics (e.g., Wu and Segerson; Wu et al.; Wu and Babcock; Antle and Capalbo). This study belongs to the second group, but focuses on an important issue that has not been fully studies in the economic literature. Specifically, this study extends Wu at al. (2004) in two important aspects. First, this study compares the relative efficiency of fertilizer-use taxes and three conservation easement policies (payments for conservation tillage, crop rotation and land retirements) for reducing nitrogen loads to the Mississippi River, while Wu et al. (2004) examine the effectiveness of payments for conservation tillage and crop rotation. Second, this study uses a state-of-art physical model to estimate NO_3-N concentrations in the Mississippi River, while Wu et al. (2004) use simply environmental production functions to estimate NO_3-N runoff beyond the root zone. Thus, this study should provide a better and more accurate measure of nitrate water pollution.

The Study Region

The Upper Mississippi River Basin (UMRB) encompasses approximately 480,000 square kilometers in six states: Illinois, Indiana, Iowa, Minnesota, Missouri, and Wisconsin[1]. The three major rivers in the UMRB are the Mississippi, the Minnesota, and the St. Croix. In this study, area above mouth of Missouri River, accounting for about 440,000 square kilometers, was used in this study. Thus, the UMRB is referred to as this area hereafter.

In the most parts of the UMRB, agriculture is the dominant land use. The latest Natural Resource Inventory reports that nearly 70 percent of total land is used for agriculture and pasture. Corn, soybean, and alfalfa are the major crops planted in the basin. Corn and soybean covers 41 percent of total land and account for 59 percent of total cropland and pastureland in the basin. Major cropping practices are corn-soybean rotations and continuous corn, accounting for 62 percent and 6 percent of total cropland and pastureland respectively. Conventional tillage is a common tillage practice, accounting for 59 percent of total land planted to row crops (corn and soybean). In particular, 86 percent of continuous corn is produced using conventional tillage. Conservation tillage, such as no-till and reduced tillage, accounts for only 41 percent of cropland in the basin[2]. About 3 percent of cropland enrolled in the Conservation Reserve Program (CRP). The annual rental rates range from $15.4 to $112.6, with an average of $78.3 in the basin.

The Modeling Framework

This section presents the integrated modeling framework to evaluate alternative policies for reducing nitrogen loads to surface water within the Upper Mississippi River Basin and Gulf of Mexico. The framework, illustrated in figure 2, is based upon the 1982, 1987, 1992 and 1997 Natural Resource Inventories (NRI) - the most comprehensive surveys of soil, water, and related resources ever conducted in the United States. The NRI, conducted by the Natural Resource Conservation Service of the U.S. Department of Agriculture, is a scientifically based, longitudinal panel survey that contains information on nearly 800,000 sample sites across the continental United States. At each site, information on nearly 200 attributes is collected, including cropping history, soil properties, and agricultural land management practices. The NRI also contains an expansion factor to indicate the acreage each site represents. Thus, total acreage in the basin can be estimated by summing up the expansion factors for all sites in the basin. In the UMRB, there are a total of 101,893 sites, of which 44,229 sites are located in agricultural land in 1997.

Using the 1982, 1987, 1992, and 1997 NRIs and economic data, the three econometric models are estimated to predict changes in land use and farming practices under alternative policies in the UMRB. These predicted changes are then fed into the physical model, the Soil and Water Assessment Tool (SWAT), to predict their impact on NO_3-N concentrations in the Mississippi River. Results are spatially displayed by the GIS interface of the SWAT model. This integrated framework allows region-scale policy simulations while incorporating site-specific information. Below, we describe in details the economic and physical models of the framework.

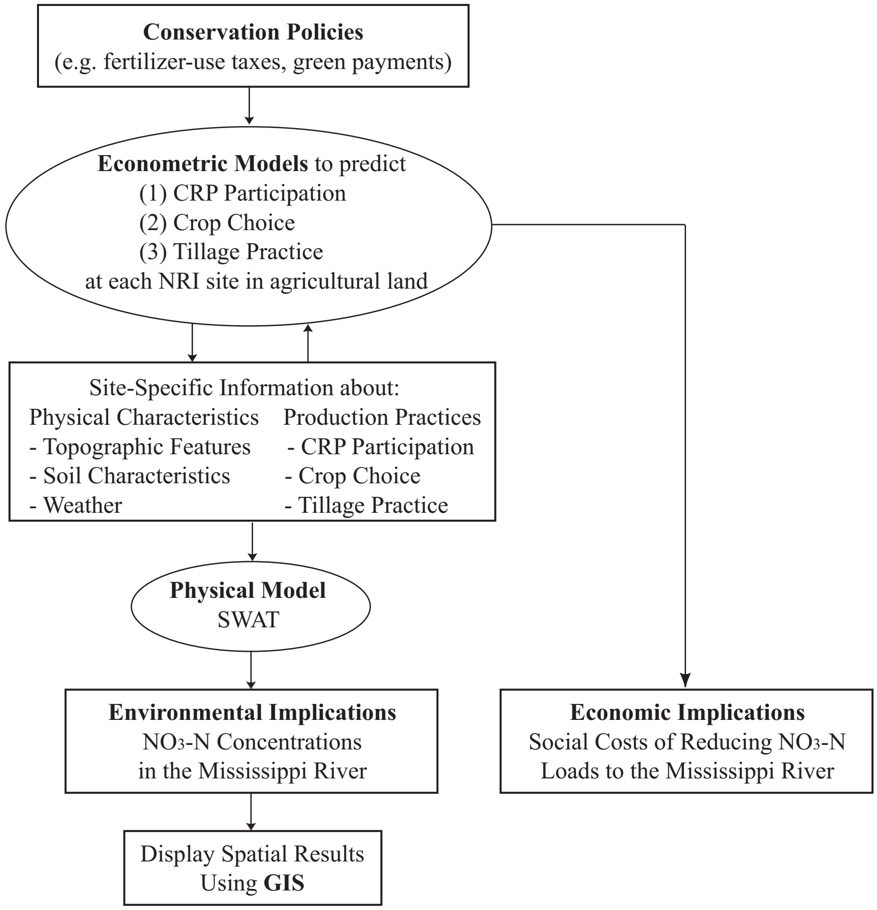

Figure 1. The Modeling Framework

The Economic models

Three econometric models are developed to predict farmers' decisions regarding: (1) the CRP participation; (2) crop choice; and (3) tillage practice. The CRP model predicts farmers' decisions as to whether or not to participate in the CRP program at each NRI site in the UMRB. The crop choice model predicts farmers' choice of crop at each NRI site (i.e. corn, soybean, hay, or other crop). The tillage model predicts farmers' choice of tillage practices (conventional or conservation tillage) at each NRI site. Each model is specified as the logistic functional form to predict probabilities of choosing alternative land use options at each NRI site:

(1) $$\text{Prob}_{ij} = \frac{\exp\left(\beta_j' x_{ij}\right)}{\sum_J \exp\left(\beta_j' x_{ij}\right)}, \quad i = 1, 2, ..., I; \; j = 1, 2, ..., J$$

where Prob_{ij} is the probability of choosing land use option *i* at NRI site *j*, and x_{ij} is a vector of independent variables affecting the farmer's choice.[3]

For the CRP model, the land use options are whether or not to participate in the CRP (i.e, I = 2). The important variables affecting farmers' CRP participation decisions include CRP rental rates and opportunity costs of participation. To measure the opportunity cost of participation, we include the following variables as independent variables in the model: a) expected revenue for corn production at the county level, b) variables measuring land quality at individual NRI sites such as land slope, erodibility, water holding capacity, organic matter percentage, soil pH, and soil permeability, c) variables measuring weather conditions and production risks such as the mean and variance of maximum temperature and precipitation during corn growing season, d) input prices, and e) state dummies reflecting differences in farming practices across states.

For the crop choice model, the land use options are whether to grow corn, soybeans, hay, or "other crops" (i.e., I =4). The types of independent variables for the crop choice model include a) expected revenue and input prices for crop production at the county level; b) variables reflecting land quality and production costs at individual NRI sites, c) variables measuring weather conditions and production risks such as the mean and variance of maximum temperature and precipitation during corn growing season, and d) state dummies reflecting differences in farming practices across states. A detailed description of the crop choice and tillage models, similar to those used in this study, can be found in Wu at al. (2004).[4]

For the tillage model, the choice is whether or not to adopt conservation tillage (i.e., I=2). The key independent variable for the tillage model is the difference in production costs between conventional and conservation tillage. Other variables affecting tillage practices include weather and soil conditions because conservation tillage is more suitable for some soils and whether conditions than for others. For example, conservation tillage is not suited for: (a) poorly drained soils; (b) less fertile soils; and (c) steep and rough areas. Under those conditions, crop yields and profits under conservation tillage may be substantially lower than under conventional tillage.

Three econometric models are used in the following order. First, the CRP model is used to predict the sites that will be enrolled in the CRP. Second, the crop choice model is applied to the non-CRP sites to predict the crop choice (corn, soybean, hay, or other crops) in 1998 and 1999. Based on the crop choice in these two years, crop rotations (corn-soybean rotations, continuous corn, hay, and other crop) at each site are determined. Third, if a site is predicted to be in corn-soybean rotation or continuous corn production, the tillage model is applied to predict the type of tillage operation (conventional tillage or conservation tillage).

Data and Estimation of the Economic Models

The estimation of the three sets of econometric models requires a substantial amount of data, which must be integrated from multiple sources. These data include a) the choice of crop, tillage and CRP participation at each NRI site, b) farmers' expected prices for inputs and outputs, c) expected yields, d) measures of production risks, e) site characteristics at each NRI point (soil properties, topographic features, climate conditions). Information on site characteristics is needed because we only have the county-level data on crop yields. Site characteristics are used to capture differences in land quality among the NRI sites. Below we provide a description of these data.

Data on crop choice, tillage practice, and CRP participation at each NRI site are derived from the NRIs. Each NRI contains crop choice information for four years (the current year plus the previous three years) and tillage information for one year. Information on CRP participation was collected only in the 1992 and 1997 NRIs. Thus, we have crop choice information for sixteen years at each NRI site, tillage information for three years,[5] and CRP participation information for two years. Pooling these time-series and cross-sectional data results in 506,652 observations for the crop choice model (42,221 agricultural NRI sites x 12 years), 126,663 observations for the tillage model (42,221 x 3), and 84,442 observations for the CRP model (42,221 x 2). For computational feasibility, we randomly selected ten percent of the observations for the estimation of these models.

The expected revenue for a crop in period *t*, $E(R_t)$, is estimated by

(2) $$E(R_t) = E(p_t)E(y_t) + \rho(p, y)\mathrm{sd}(p_t)\mathrm{sd}(y_t)$$

where $E(p_t)$ is the expected price, $E(y_t)$ is the expected yield, and $\mathrm{sd}(p_t)$ and $\mathrm{sd}(y_t)$ are standard deviation of the price and yield, respectively. ρ is the correlation coefficient between the price and yield, which is assumed to be constant over the estimation period. The expected price is estimated using the futures price reported from the Chicago Board of Trade (CBT). Specifically, the first and second Thursday closing prices in March for December corn are averaged for each year. The expected value and the standard deviation of corn yield are estimated for each county using the National Agricultural Statistics Service (NASS) county crop data for the period of 1975-1998. Using the data, a trend model of $y = \alpha + \beta t + \varepsilon$ is estimated for corn yields using the ordinary least square (Chavas and Holt 1990). The predicted value is taken as expected corn yield. The estimated residuals are then used to derive the standard deviation of corn yield, which reflects farmers' risk in growing corn in each county. The standard deviation of corn price is estimated based on adaptive expectations following Chavas and Holt (1990). Specifically, the standard deviation of corn price in period *t* is given by

$$\text{sd}(p_t) = \left[\sum_{j=1}^{3} \omega_j \left(p_{t-j} - E_{t-j-1}(p_{t-j}) \right)^2 \right]^{0.5} \tag{3}$$

where p_{t-j} is the annual average market price for corn in period *t-j*, $E_{t-j-1}(p_{t-j})$ is its expectation in the previous year. The year-specific weights ω_j , 0.5, 0.33, and 0.17 are also adapted from Chaves and Holt (1990). Because the expected revenues for corn and soybean are highly correlated, only the expected revenue for corn is included as independent variable. Also, the expected revenue for hay was statistically insignificant and was dropped from the final model.

The CRP annual rental payments are obtained from the FSA. Time-series data on wage rate and fertilizer prices are obtained from the National Agricultural Statistic Service. All input and output prices, and the CRP rental rates are normalized by the index of prices paid by farmers, taken from the Agricultural Statistics.

The NRI also contains information about land characteristics at each NRI site, which include land capacity class, slope, and erodibility index for wind and water erosion. Other site-specific characteristics such as water holding capacity, organic matter percentage, soil pH, and soil permeability are obtained by linking NRI to the SOIL5 database developed by the NRCS. Weather data are obtained from the Midwestern Regional Climate Center. Using historical weather information from the nearest weather station, the mean and standard deviation of maximum daily temperatures and precipitation during corn growing season are estimated.

The Physical Model

The Soil and Water Assessment Tool (SWAT) is used to assess the level of NO_3-N concentrations in the Mississippi River under different policies. SWAT is a watershed (or river basin) scale water balance simulation model, developed by the Agricultural Research Service (ARS). SWAT can predict the impact of crop management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land use, and management conditions over a long period of time (Neitsch et al). Because SWAT is a physically based model, no regression equation is used to describe the relationship between input and output variables. Instead, SWAT requires extensive information on topography, soil properties, weather, and land management practices in the watershed. The physical process associated with water movement, sediment and chemical transports, and crop growth are directly modeled by SWAT using collected information.

The physically based approach has two desirable properties. First, watershed with no monitoring data (e.g. stream gage data) can be modeled. Secondly, the relative impact of alternative input data (e.g. changes in land management practices, climate, etc.) on water quality can be quantified (Neitsch et al.). This study cannot be completed without the second property.

The spatial units of SWAT simulations are watershed and subbasins. The watershed is the overall hydrological unit, representing the entire area to be simulated. The watershed can be partitioned into a number of subbasins. Each subbasin possesses a geographic position in the watershed and is spatially related to adjacent subbasins. For example, outflow from subbasin #1 enters subbasin #3. Each subbasin is further divided into hydrologic response units (HRUs), which are virtual units of SWAT simulations. The geographical locations of HRUs within a subbasin are not specified. Each HRU represents a unique combination of land use and soil type. For example, if a subbasin has two land uses and two types of soil, SWAT will construct four HRUs for the subbasin, each HRU represents a unique combination of land use and soil class. The inclusion of HRUs enables SWAT to account for the complexity of the landscape within the subbasins. Thus, SWAT can take two levels of the spatial heterogeneity into account. The first level (subbasin) supports the spatial heterogeneity associated with hydrology, and the second level (HRU) incorporates the spatial heterogeneity associated with land use and soil type. Since the spatial heterogeneity significantly affects the levels of runoff, leaching, and the associated agricultural pollutants, SWAT is one of the best available tools for analyzing the issues related to agricultural land use changes and water pollution under spatially heterogeneous conditions.

SWAT requires extensive information on the watershed, such as topography, land use and management, soil properties, and weather. Collected information are applied in three steps in the model development. These three steps include: (1) watershed delineation; (2) land use and soil classification; and (3) land management schedule descriptions. This study uses ArcView interface of SWAT 2000 (AVSWAT) to automate most of the model development steps. Detailed descriptions about these steps are documented in Anonymous (2004a, 2004b).[6] Delineated 118 subbasins, very close to USGS's 8-digit hydrologic polygons, are presented in figure 8.

Methods for Policy Evaluation

Using the integrated modeling framework, we evaluate the relative efficiency of four commonly suggested policies for controlling hypoxia in the Gulf of Mexico: (1) taxes on chemical fertilizer use; (2) incentive payments for cropland retirement; (3) incentive payments for conservation tillage; and (4) incentive payments for corn-soybean rotations. The evaluation is based on their social costs for achieving different levels of reduction in NO_3-N concentrations in the Mississippi River. The impacts of these policies on crop choices, CRP participation, and rotation and tillage practices, and farm income are also estimated.

To evaluate the impacts of the policies, we must first establish a baseline. To do this, we use the estimated models to predict farmer's land use and management practices in 1998 and 1999. Specifically, by substituting the values of independent variables in 1998 and 1999 into the three econometric models, the probabilities of farmers' choice of each land use option in 1998 and 1999 are calculated for each NRI point. The total acres of CRP, individual crops and conservation tillage in a region (e.g., a HRU) are then estimated using the following equations:

(4) $$A_{CRP} = \sum_j \text{Prob}(CRP)_j * xfactor_j \ ,$$

(5) $$A_i = \sum_j \text{Prob}(crop\ i)_j * xfactor_j \ ,$$

(6) $$A_{conserv} = \sum_j \sum_{i=1}^{N} \text{Prob}(conservation\ tillage \,|\, crop\ i)_j * \text{Prob}(crop\ i)_j * xfactor_j \ ,$$

where the summation for *j* is over all NRI sites within the region, A_{CRP} is the total CRP acres, A_i is the total acreage of crop *i*, and $A_{conserv}$ is the total acreage under conservation tillage.

Based on farmers' crop choices at each NRI point in 1998 and 1999, the probabilities of adopting alternative cropping systems at each NRI site are estimated using the following formula:

(7) $$\begin{aligned} Prob(corn\text{-}bean\ rotation)_j = {} & Prob(corn\ in\ 98 \,|\, crop\ choice\ in\ 97)_j \\ & * Prob(soyb\ in\ 99 \,|\, corn\ in\ 98)_j \\ & + Prob(soyb\ in\ 98 \,|\, crop\ choice\ in\ 97)_j \\ & * Prob(corn\ in\ 99 \,|\, Soyb\ in\ 98)_j \end{aligned}$$

Based on the crop rotation at each NRI point, the acreage of land under a corn-soybean rotation is then estimated:

(8) $$A_{corn-bean\ rotation} = \sum_j \Pr ob(\text{corn-soyb rotation})_j * xfactor_j \ ,$$

Acres of continuous corn and continuous soybeans are estimated in a similar way. Based on the land use predictions for each HRU from equations (4)-(8), SWAT is then run to predict NO_3-N concentrations in the Mississippi River. These estimates from econometric models and SWAT simulations serve as a baseline or reference for measuring the policy impacts.

Once the baseline is established, the policy impact on land use can be evaluated. Some independent variables in the econometric models are "policy variables" because they are directly affected by policies. For example, policymakers can increase CRP participation by raising CRP rental payments. The effect of this policy is simulated by increasing CRP rental rates in the CRP model, holding other variables constant. Similarly, in the incentive payment programs for crop rotations, farmers who grow soybeans after corn or corn after soybean receive a payment. The effects of the payments are simulated by increasing the expected revenue for the eligible crops in the crop choice model (soybeans after corn or corn after soybean) by the amount of the payments. In the payment program for conservation tillage, farmers adopting conservation tillage receive a payment. The effect of this payment is simulated by increasing the difference between the production costs for conventional tillage and conservation tillage in the tillage model by the amount of the conservation payments. By setting the "policy variables" to a range of values, supply curves are generated for CRP acreage, crop rotation, and conservation tillage. These supply curves show acreages of adoption of conservation practice under different levels of incentive payments (see the curve above the horizontal axes in figure 2 for an illustration). Changes in land use are then translated into corresponding changes in NO_3-N concentrations in the Mississippi River through SWAT simulations. Results are generated for percentage reductions in NO_3-N concentrations (simulated 20-year average) under the different levels of adoption of conservation practice (see the curve below the horizontal axes in figure 2).

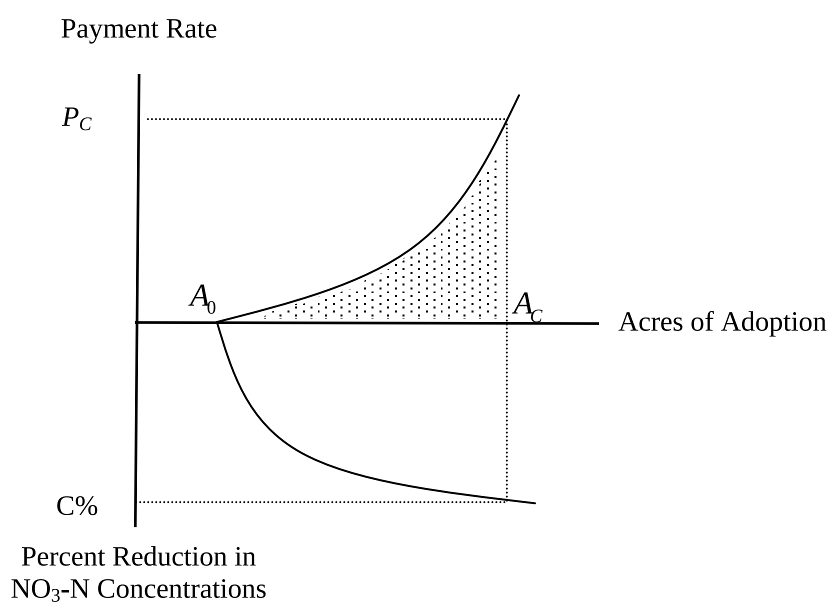

Figure 2. Measuring Social Costs for Reducing NO_3-N Concentrations

Social cost for achieving different levels of reduction in NO_3-N concentrations can be estimated based on the estimated the relationships between payment levels, adoption rates, and percentage reductions in NO_3-N concentrations. Specifically, for each targeted level of reduction in NO_3-N concentrations, the required adoption level can be determined based the relationship between adoption rates and percentage reductions in NO_3-N concentrations (i.e., the curve below the horizontal axis in figure 2). The corresponding payment level is then determined based the supply curve of conservation practice (i.e., the curve above the horizontal axis in figure 2). For example, as shown in figure 2, a C% reduction in NO_3-N concentration requires A_C acres of land adopting the conservation practice. The corresponding payment rate required is \$ P_C . The area under the supply curve between the vertical axes and the required adoption level in figure 2 (i,e., the shaded area) is the social cost for achieving the targeted level of reduction in NO_3-N concentration.

Social costs for achieving different level of reduction in NO_3-N concentrations under the fertilizer-use tax are estimated using the following procedure. First, we estimate crop choice at each NRI site for different tax rates τ by changing the fertilizer price in the crop choice model. Second, we estimate the fertilizer application rate for corn by using $N(\tau) = N_0(1+\tau)^{-\varepsilon}$, where N_0 is the nitrogen application rate without any tax, τ is the tax rate, and ε is the own price elasticity of nitrogen application rate. We set N_0 = 201 Kg pa^{-1} based on suggestions from a researcher at the Soil and Water Conservation Society and data from Iowa Agricultural Experimental Station, and ε = -0.21 based on a study of demand for nitrogen fertilizer in corn production in the U.S. Midwest by Denabaly and Vroomen (1993). Third, based on the estimated crop choice and nitrogen application rates, we rerun SWAT to estimate the NO_3-N concentrations in the Mississippi River under different levels of taxes. Fourth, we calculate aggregate farm profit under different tax rates using

(9) $$\sum_{i=1}^{I}\left\{A_i(\tau)\left[p_iY_i(N_i(\tau)) - C_i - (1+\tau)wN_i(\tau)\right]\right\}$$

where $A_i(\tau)$ is the total acreage planted to crop *i* under the tax p_i is the price for crop *i*, $Y_i(N_i(\tau))$ is the yield of crop *i* under the fertilizer tax, and C_i is the production cost of producing crop *i* except the nitrogen fertilizer. $A_i(\tau)$ is estimated from the crop choice model and (5). Corn yields under different levels of nitrogen application rates $Y_i(N_i(\tau))$ are taken from Stecker et al (1995), who estimate quadratic yield response functions to nitrogen application rates for continuous corn and corn-soybean rotation. Yields for other crops are assumed not to be affected by the tax. Production costs C_i are estimated based on Duffy (2000). All prices and yields except corn are obtained from the National Agricultural Statistic Service (2001). Finally, Social costs for achieving different levels of reduction in NO_3-N concentrations are estimated by subtracting the tax revenue from farmers' profit loss under the corresponding level of tax.

Results 1: The Relative Efficiency of the Four Conservation Policies

Land Use Changes under the Policies

The policy impacts on land use and farming practices in the UMRB are evaluated using the three sets of econometric models. Figure 3 presents the estimated effects of the fertilizer-use tax on cropland allocation. The predicted acreages of corn, soybean, and hay at the baseline closely match the acreages reported in the 1997 NRI. Under this policy, corn and soybean acreages decrease as the tax rate increases, while hay and other crop acreages increase simultaneously. This result is as expected because corn and soybeans are chemical-intensive crops, whereas hay and other small crops in the region are not. Also as expected, corn acreage is more responsive to the tax than soybean acreage, because corn requires more fertilizer application than soybeans. Overall, farmers are responsive to this tax; as the tax rate increases, farmers switch more "polluting" crops (i.e. corn and soybean) to "non-polluting" crops (i.e., hay and other crops).

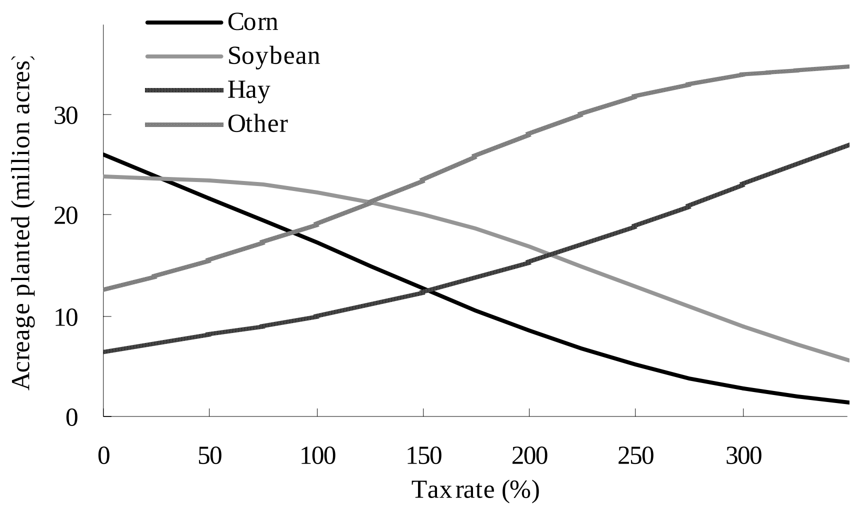

Figure 3. Estimated Acreage Responses to the Fertilizer-Use Tax
In the Upper Mississippi River Basin

Figure 4 shows the estimated effects of CRP rental rates on CRP acreage in the UMRB. As the rental rate increases, the acres of cropland enrolled in CRP also increase, but the rate of increase is not constant. Acreage responses are inelastic when the rental rate is below $100 or between $200 and $250, but elastic when the rental rate is between $100 and $200 or above $250 per acre. Most of land enrolled in the CRP from $100-$200 is used to produce hay and "other crops" before the retirement. Corn and soybean acreages are not

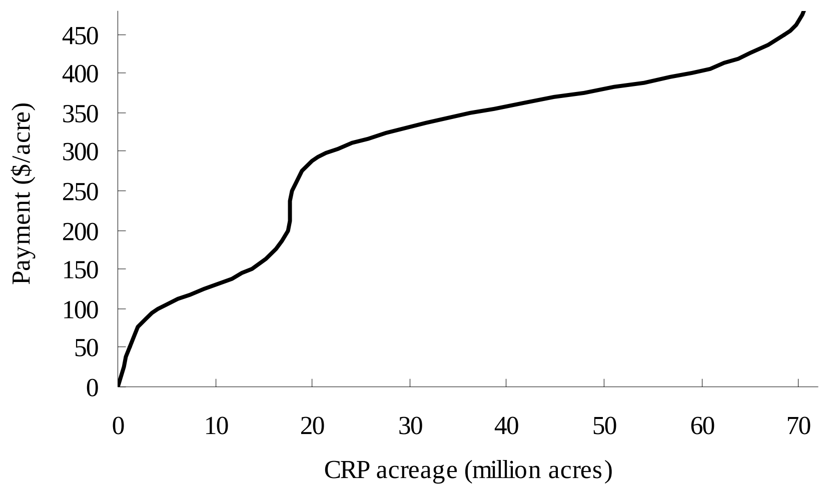

Figure 4. Estimated Supply Function of CRP Land
in the Upper Mississippi River Basin

responsive when the payment level is below $250 per acre. At the rental rate of $250, nearly 18 million acres (25 percent of cropland) is enrolled in CRP, but most of land enrolled was planted to "non-polluting crops" (i.e. hay and other crops). This suggests that required payments for CRP participation are higher than profit forgone because the average net return from corn and soybean production in the U.S. is estimated to be only $110 per acre in 1998 (Food and Agricultural Policy Research Institute 1999). Higher rental rates may be necessary for at least two reasons. First, although the CRP provides cost-share assistance to participating farmers who establish resource-conserving cover on their CRP land, this assistance covers only up to 50 percent of the participants' costs. Data obtained from the Farm Service Agency (2003) indicates that CRP participants receive $145 dollars per acre on average for cost-share assistance and incentive payments. Second, when CRP contracts expire, some farmers may want to bring their CRP land back into crop production. The conversion cost could be substantial especially when trees were planted as a land covers. Farmers may not be willing to participate if these conversion and establishment costs are covered.

Figure 5 depicts the estimated effects of incentive payments for conservation tillage in the UMRB. Farmers are very responsive to this policy. At the baseline, 40% of corn and soybean acres are adopting conservation tillage. A payment rate of $50 and $100 per acre increases the share of conservation tillage to 61 and 78 percent of corn and soybean acres, respectively. The large variation in the required payment level for conservation tillage may reflect that conservation tillage may be more suitable for some soils than for others. In general, conservation tillage is not suited for: (a) poorly drained soils; (b) less fertile soils; and (c) steep and rough areas. Under those conditions, crop yields and profits under conservation tillage may be substantially lower than under conventional tillage. In addition, conservation tillage requires special equipments such as a no-till planter and shielded sprayer. It also requires timely weed control, which some farmers, especially past-time farmers, may not be able to do.

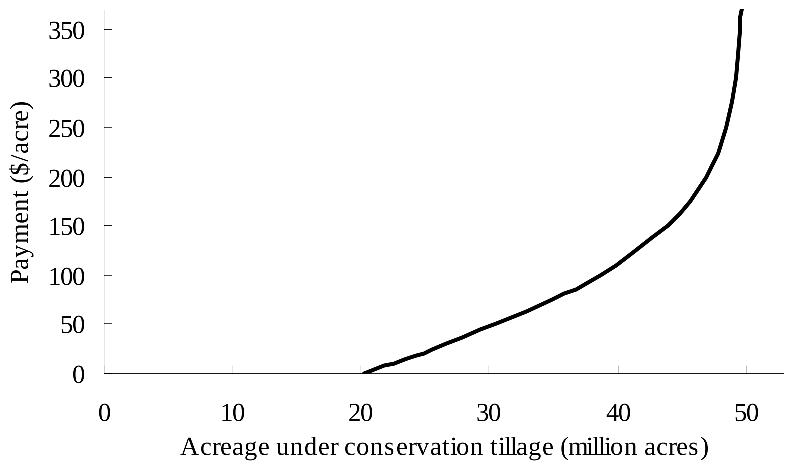

Figure 5. Estimated Acreage Responses to Incentive Payments for Conservation Tillage in the Upper Mississippi River Basin

In studying conservation tillage adoption in Iowa, Kurkalova, Kling and Zhao (2003) find that a 30 percent increase in conservation tillage can be achieved with a payment of $11 per acre. Our estimates of required payments for the UMRB are higher; a payment of $33 per acre is required for a 30 percent increase in conservation tillage in the UMRB. The difference may be due to two reasons. First, in Kurkalova, Kling and Zhao (2003), payments are offered for all crops adopting conservation tillage, while payments in this study are only offered for corn and soybean. Second, the adoption rate of conservation tillage has been historically higher in Iowa than any other states in the UMRB. The 1992 NRI indicates that conservation tillage acreage accounts for 61 percent of cropland in Iowa, but only 21 percent in other five states (Illinois, Indiana, Minnesota, Missouri, and Wisconsin).

Figure 6 presents the estimated effects of incentive payments for corn-soybean rotations. This policy rewards farmers who plant corn after soybeans, or soybeans after corn. The effects are simulated by raising the expected revenue for the eligible crops (corn after soybean or soybean after corn) in the crop choice model. Currently, 86 percent of corn and soybean acreage is under corn-soybean rotation. A payment of $50, $100, and $150 per acre increases the share to 88, 90, and 94 percent, respectively. Given that 86 percent of corn and soybean acreage is already under corn-soybean rotation, this policy is not likely to have a large impact on NO_3-N pollution, a topic which we will focus on later in this paper.

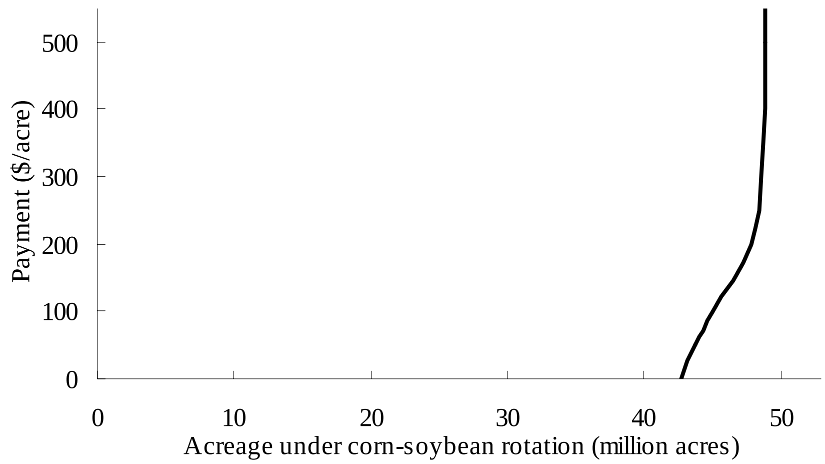

Figure 6. Estimated Acreage Responses to Incentive Payments for Corn-Soybean Rotation in the Upper Mississippi River Basin

SWAT Model Validation and Results

Using the land use data at the baseline, a 20-year run of the SWAT model is conducted. The monthly averages of the simulated stream flow are compared with the monthly average of measured stream flow from 1980 to 1999 at the USGS stream gage station on the Mississippi River in the town of Grafton, Illinois (figure 7). Although the model tends to underpredict in late winter and early spring, and overpredict in early winter, this divergence can be explained by the difference in the measured and simulated levels of precipitation. Overall, SWAT predicts the stream flow reasonably well. In addition, the difference between the measured and simulated annual average of stream flow is less than 5 percent.

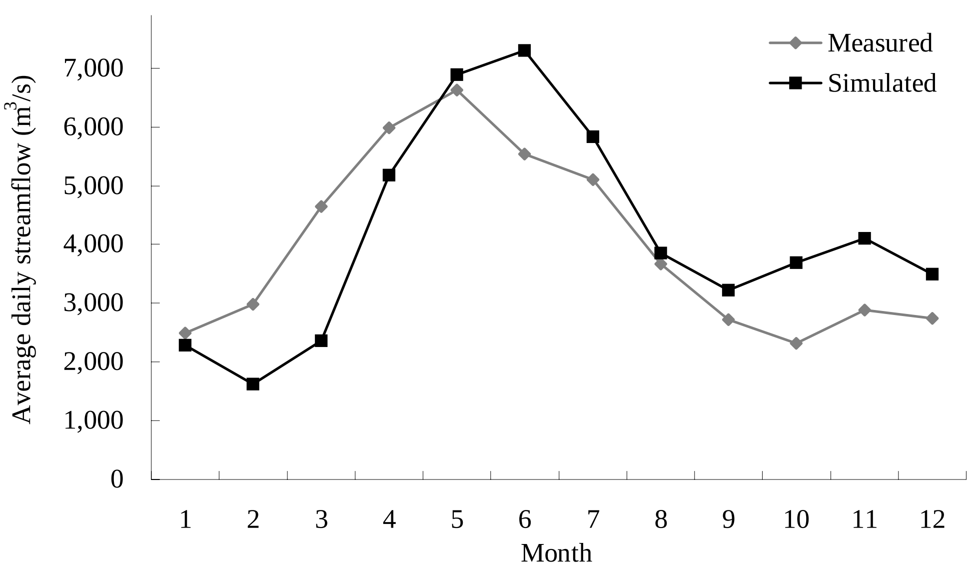

Figure 7. Monthly Average of Measured and Simulated Streamflow of the Mississippi River at Grafton, IL (R^2=0.59)

The simulated NO_3-N concentrations are also compared with measured NO_3-N concentrations at the USGS stream gage station near Grafton, Illinois. SWAT predicts an annual average of NO_3-N concentrations of 1.99 milligram per liter (mg/L), accounting for 64 percent of total concentrations of 3.14 mg/L.[7] Goolsby and Battaglin (2003) reports that commercial nitrogen fertilizer and legume nitrogen fixing contribute 65 percent of total nitrogen inputs in Mississippi River Basin above Missouri River. Because other major nitrogen inputs, such as livestock manure, human domestic waste, and industrial point source discharges, are not included in this study, NO_3-N concentrations simulated by the SWAT model is quite consistent with the study by Goolsby and Battaglin.

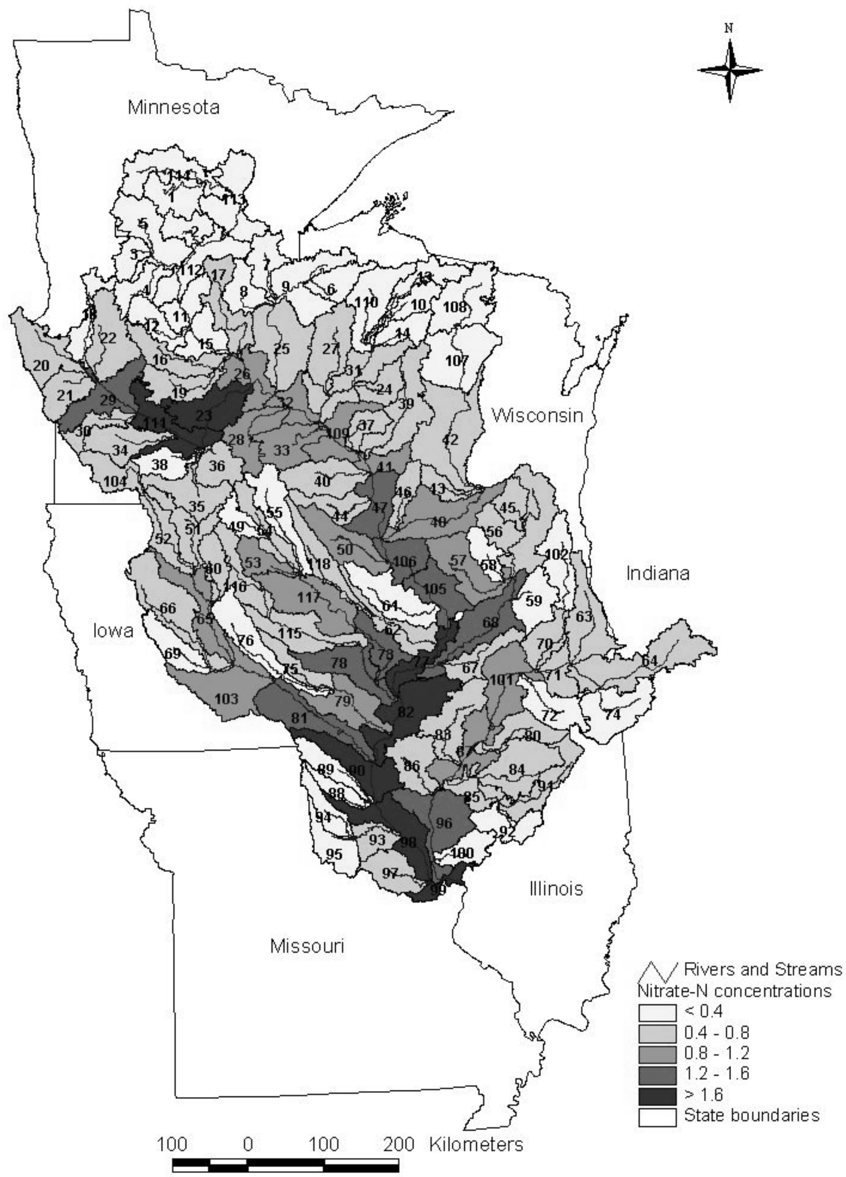

Figure 8. Estimated NO_3-N Concentration at the End of Reach in Each Subbasin in the Upper Mississippi River Basin

Figure 8 shows the simulated NO_3-N concentrations at the end of reaches in each subbasin in the UMRB. The level of concentrations range from 0.18 to 2.1 mg/L, with a basin average of 0.7 mg/L. High NO_3-N concentrations tend to occur along the mainstream of the Mississippi River and its major tributaries. In the upper area of the basin, particularly high concentrations are predicted in subbasins 111 and 23. These subbasins have intensive row crop production and higher precipitations than the basin average. Lower concentrations occurs at many subbasins below these subbasins due mainly to less intensive row crop production. In the UMRB, the highest concentrations occur in subbasin 90, the confluence of the Mississippi River and the Des Moines River. The subbasins along the Des Moines River have high concentrations of row crop production (mostly corn and soybean) and have been identified as a high-risk area of NO_3-N water pollution in the UMRB. Previous water quality surveys show that NO_3-N concentrations in the public water supply in Des Moines, Iowa, often exceed the maximum contamination level of 10 mg/L set by the EPA (USGS 2003).

The Relative Efficiency of the Four Policies

Social costs to achieve different levels of reduction in NO_3-N concentrations in the Mississippi River under each of the four policies are shown in figure 9. The fertilizer-use tax is estimated to be most cost-effective for reducing NO_3-N concentrations in the Mississippi River among the four policies. This result reflects that acreage of polluting crops (corn and soybean) is more responsive to the tax than to the three payment policies. In addition, this policy reduces the amount of fertilizer application. In contrast, the CRP is the least cost-effective for reducing NO_3-N concentrations in the Mississippi River. Although the CRP can be used to achieve a large reduction in NO_3-N concentrations in this river, it has to enroll the non-polluting crops first. Our results show that few acres of polluting crops will be enrolled in the CRP when the rental rate is below $250 per acre in the basin.

Among the three conservation easements, incentive payments for conservation tillage are most cost-effective for reducing NO_3-N concentrations in the Mississippi River. Although the payment is less cost-effective than the fertilizer-use tax, the social cost under this policy is significantly lower than those under the other two conservation easements. It should be noted, however, that this policy can reduce NO_3-N concentrations by no more than 37 percent. At this level, all cropland under conventional tillage has already been converted to conservation tillage.

Finally, our results suggest that incentive payments for corn-soybean rotations can reduce NO_3-N concentrations up to only 6 percent in this basin. Further reduction is not possible because, at this level, all continuous corn has already been converted to corn-soybean rotation. Such a small effect on stream water quality is expected since 86 percent of corn and soybean acres are already in corn-soybean rotations.

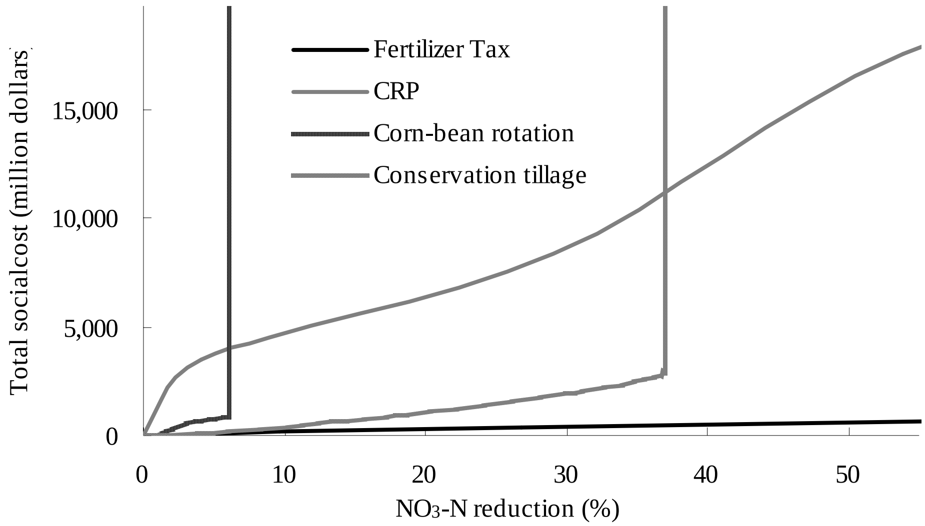

Figure 9. Estimated Social Costs for Reducing NO_3-N Concentrations in the Upper Mississippi River Under the Four Policies

Results 2: The Relative Efficiency of the Targeted and Uniform Taxes

Results reported in previous section show that the uniform fertilizer-use tax is much more cost-effective than any of conservation payments for reducing NO_3-N concentrations in the Mississippi River. However, results does consider other tax policies, such as a targeted fertilizer-use tax. The extent to which a targeted tax outperforms a uniform tax is in dispute. Claassen and Horan (2001) find that the targeted tax significantly outperforms the uniform tax under spatially heterogeneous conditions. In contrast, Helfand and House (1995) find that the uniform tax is almost as cost-effective as the targeted tax. Our second integrated model evaluates the relative efficiency of the targeted and uniform taxes for reducing NO_3-N surface loads using the integrated modeling framework To facilitate our analysis, this section focuses on the Des Moines Watershed, simulated to be the most NO_3-N polluted watershed in the UMRB.[8]

Although the second integrated model follows basically our first model, we made several changes in the physical model to enhance the accuracy of SWAT simulation. First, land use information is derived from the National Land Cover Dataset (NLCD) instead of the LULC. The NLCD is a 30-meter resolution raster land cover for the entire United States. The NLCD provides detailed land use for agriculture (row crop and hay), forest, wetland, urban, and other land uses. Second, land management scenarios for polluting crops (continuous corn and corn-soybean rotation) incorporates the split nitrogen applications. Third, we obtained the daily values of maximum and minimum daily temperature and precipitation from Iowa Environmental

Mesonet. Thus, the SWAT simulation is based on historical climatic conditions rather than randomly generated climatic variables

SWAT Model Validation and Results

Using the land use information under the baseline scenario, the SWAT model is run for the period of 1988-1999. Simulated monthly average streamflow is compared to measured values reported from the USGS stream gage station on the Des Moines River in Ottumwa, Iowa (figure 10). Overall performance of the SWAT prediction is quite reasonable (R^2=0.88). Although the model overpredict during post- and pre-harvesting seasons, the difference between the simulated and measured annual average streamflow is less than 4 percent. The model's prediction is particularly well for the period of 1999 (R^2=0.95). Thus, we use the values predicted for this period to estimate NO_3-N runoff from the watershed.

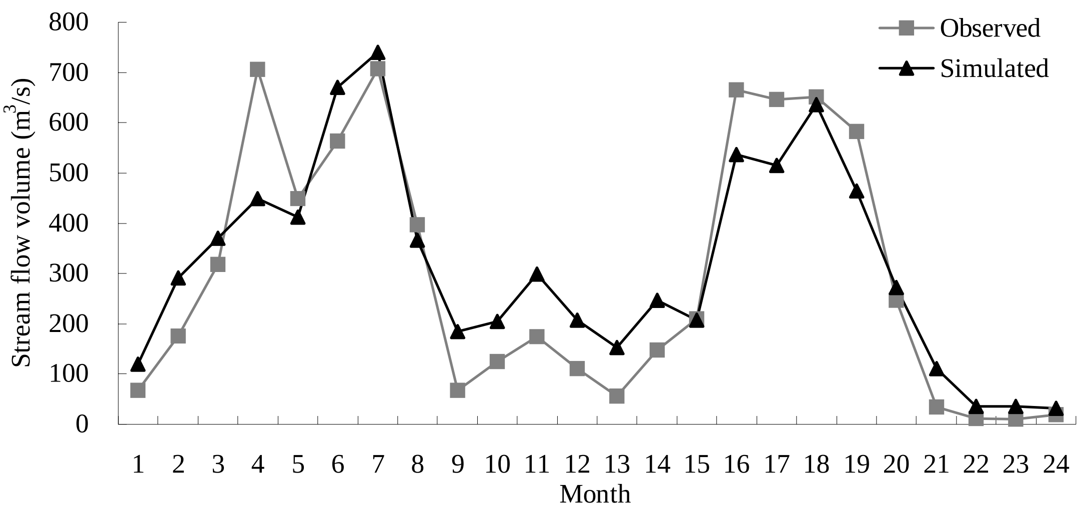

Figure 10. Simulated and Observed Streamflow in the Des Moines River at Ottumwa, Iowa 1998-99 (R^2 = 0.88)

Table 1 shows the average annual NO_3-N runoff from different land use. The level of runoff from land planted to row crops is generally high. Particularly high levels of runoff are predicted from land adopting conventional tillage, estimated to be 4.4 Kg ha^{-1} and 2.7 Kg ha^{-1} from continuous corn and corn-soybean rotation, respectively. NO_3-N runoff from the land adopting conservation tillage are generally lower, 2.2 Kg ha^{-1} and 1.0 Kg ha^{-1} from continuous corn and corn-soybean rotation, respectively. The model estimates that NO_3-N runoff from continuous corn is 122 percent higher than corn-soybean rotation. This difference may be due to fertilizer management. Continuous corn production requires the application of nitrogen fertilizer every year, nitrogen fertilizer is usually applied every other year under corn-soybean rotation (i.e. fertilizer is applied only when corn is planted). NO_3-N runoff from hay and other crops is the lowest among alternative cropping systems. This is expected because hay and other crops do not require nitrogen application. Thus, the only source of NO_3-N runoff is nitrogen fixation. Overall, NO_3-N runoff from row crops is estimated to be 30 times higher than hay and other crop, which is consistent with the prior literature. For example, Randall et al. (1997) report that NO_3-N runoff from row crops is 30 to 50 times higher than from the perennial crops.

Table 1. Predicted NO_3-N Runoff Under Different Agricultural Land Use in the Des Moines Watershed (Kg ha^{-1})

	Subbasin									
Land use	51	52	60	65	66	69	81	103	104	Average
Corn-soybean - CT	2.3	2.9	3.0	3.9	2.4	2.6	1.2	2.3	3.5	2.6
Corn-soybean - NT	1.3	0.9	1.1	1.4	1.1	1.1	0.6	0.9	1.1	1.1
Continuous corn - CT	4.2	4.6	4.2	5.8	4.1	4.4	1.7	4.3	6.6	4.1
Continuous corn - NT	2.7	1.5	1.9	3.2	2.2	1.8	0.9	2.3	2.9	2.0
Hay and pasture	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
Average	2.1	2.0	2.1	2.9	2.0	2.0	0.9	2.0	2.8	2.0

Table 1 also shows a considerable difference in NO_3-N runoff among 9 subbasins in the Des Moines Watershed. The predicted runoff ranges from 0.9 Kg ha^{-1} to 2.9 Kg ha^{-1}. The highest runoff is predicted in subbasin 65, in which row crops are intensively planted In addition, annual precipitation in this subbasin is higher than any other subbasins in the watershed. In contrast, the lowest NO_3-N runoff is predicted in the subbasin 81, in which row crop production is less intensive. Furthermore, annual precipitation in this subbasin is lower than watershed average. Overall, high levels of NO_3-N runoff are predicted in the middle of the watershed, and low levels of runoff are estimated in the upper and lower areas of the watershed. This spatial variation can be mainly explained by cropping patterns and precipitation.

The high degree of variation in NO_3-N runoff is particularly interesting. Because it is assumed that farmers in the watershed treat their lands uniformly for given land use, variation in NO_3-N runoff is due to the physical attributes and operational characteristics (e.g. soil properties, land slope, weather conditions, and cropping patterns). Thus, the estimated variation in NO_3-N runoff can be viewed as a degree of spatial heterogeneity in the watershed. In this context, spatial heterogeneity in the Des Moines Watershed is considerable, implying a significant efficiency gain from the targeted fertilizer-use tax.

The Relative Efficiency of the Fertilizer-Use Taxes

Figure 11 illustrates derivation of optimal tax rates under the targeted policy. For simplicity, it is assumed that there are two subbasins in the watershed. The curves ML_1 and ML_2 represent marginal profit loss for reducing NO_3-N runoff from subbasin 1 and 2, respectively. The aggregate supply of NO_3-N runoff reduction is given by the horizontal summation of these two curves. Assume that the policymaker wishes to reduce NO_3-N runoff by $\overline{R}$ in the watershed. To minimize the aggregate farm profit loss, R_1 and R_2 are the levels of NO_3-N runoff reduction for subbasin 1 and 2, respectively. In the lower figure, S_1 and S_2 are the curves representing the relationship between the tax rate and corresponding NO_3-N runoff reduction for subbasin 1 and 2. To reduce runoff by R_1 and R_2, the tax rates should be τ_1^* and τ_2^* for subbasin 1 and 2, respectively.

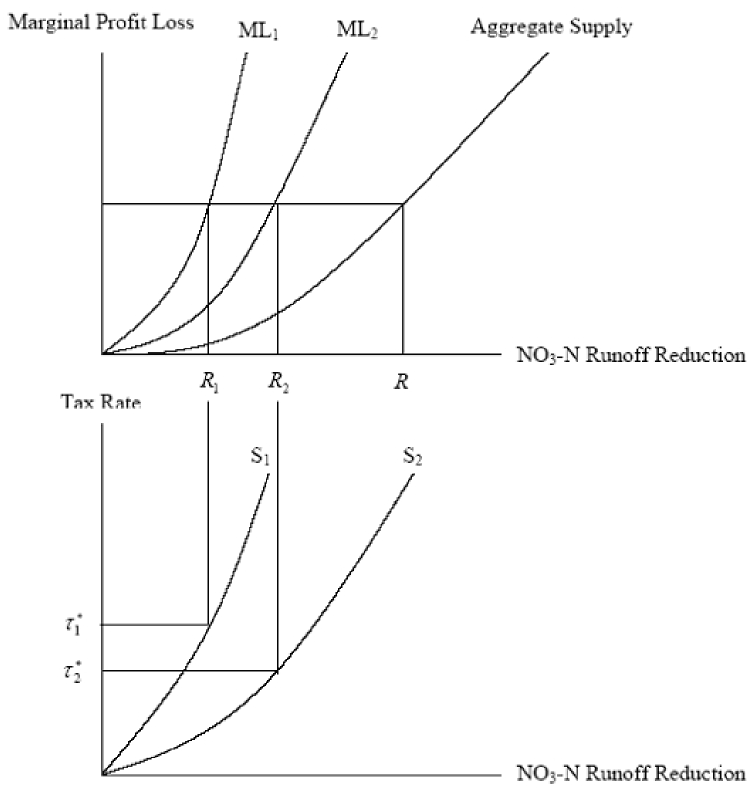

Figure 11. Optimal Tax Rates Under the Targeted Fertilizer-Use Tax

Table 2 shows the optimal tax rates for each of 9 subbasins under the targeted fertilizer-use tax. Under this policy, the highest tax rate is imposed on subbasin 65, and the lowest for subbasin 81 to achieve each of NO_3-N runoff reduction targets. SWAT model predicts that subbasin 65 has the highest NO_3-N runoff potential (2.9 Kg ha^{-1}), and thus more likely to contribute to water pollution than any other subbasins in the watershed. In contrast, subbasin 81 is predicted to have the lowest NO_3-N runoff potential (0.9 Kg ha^{-1}), and thus less likely to contribute to water pollution. Overall, the variation of tax rates among subbasins is quite consistent with the variation of NO_3-N runoff. The tax rates under the targeted policy are generally lower than the uniform policy, except three subbasins with high NO_3-N runoff potentials.

Table 2. Optimal Tax Rates Under the Targeted and Uniform Polices

		NO3-N Runoff Reduction From the Watershed (%)				
		10	20	30	40	50
Uniform tax (%)		83	149	173	194	205
Targeted tax (%)	Subbasin					
	51	66	118	142	160	176
	52	67	120	140	166	180
	60	84	151	183	202	218
	65	92	164	195	214	232
	66	75	135	165	180	198
	69	63	113	138	153	169
	81	51	92	117	137	143
	103	57	102	126	141	156
	104	88	163	191	212	231

Table 3 presents the farm profit loss for each subbasin under the targeted and uniform fertilizer-use taxes to reduce NO_3-N runoff by 30 percent. It is shown that 6 out of 9 subbasins in the Des Moines Watershed are better off under the targeted policy. In particular, subbasin 81 and 103 reduce profit loss substantially, by more than 100 percent. In contrast, 3 out of 9 subbasins in the watershed are worse off under the targeted policy. These subbasins are predicted to have high NO_3-N runoff potentials, and thus high tax rates are imposed under the targeted policy. Overall, the efficiency gain under the targeted fertilizer-use tax is considerably high. The difference in the aggregate farm profit loss between the targeted and uniform policies is estimated to be 30 percent.

Table 3. Aggregate Farm Profit Loss Under the Targeted and Uniform Taxes for 30 percent NO_3-N Runoff Reduction in the Des Moines Watershed

	Profit loss			NO3-N runoff reduction		
Subbasin	Uniform	Targeted	Difference (%)	Uniform	Targeted	Difference (%)
51	690,613	463,583	-49.0	119,946	87,333	-37.3
52	506,758	297,157	-70.5	126,231	81,437	-55.0
60	448,661	503,115	10.8	33,262	76,607	56.6
65	540,703	641,795	15.8	136,932	218,327	37.3
66	817,761	749,916	-9.0	103,256	89,626	-15.2
69	663,541	334,561	-98.3	79,371	28,269	-180.8
81	710,933	233,882	-204.0	74,224	27,711	-167.9
103	981,213	359,140	-173.2	136,039	55,735	-144.1
104	1,049,321	1,366,796	23.2	428,496	572,607	25.2
Watershed	6,409,505	4,949,945	-29.5	1,237,759	1,237,651	0.0

Finally, figure 12 draws two curves representing the relationship between the NO_3-N reduction and aggregate farm profit loss under the targeted and uniform taxes in the Des Moines Watershed. Although the difference in the aggregate farm profit loss between two policies is small when the reduction target is low, profit loss under the targeted policy is significantly smaller than uniform policy when the reduction target is more than 20 percent. To reduce runoff from the watershed by 30 to 50 percent, the differences in profit loss under two taxes are estimated to be about 30 percent in the Des Moines Watershed.

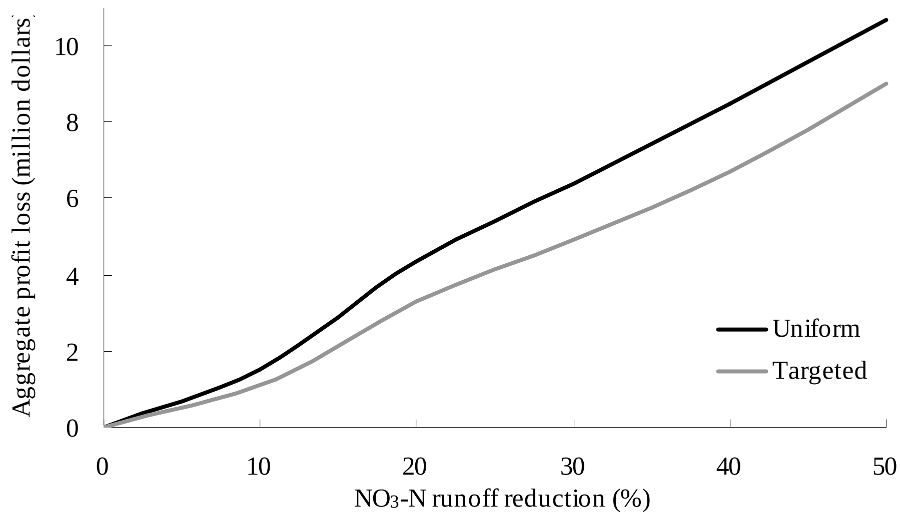

Figure 12. Aggregate Farm Profit Loss Under the Targeted and Uniform Taxes in the Des Moines Watershed

Conclusions

This study integrates economic and physical models to estimate the social costs for reducing NO_3-N concentrations in the Upper Mississippi River Basin under four commonly suggested policies for controlling hypoxia in the Gulf of Mexico. The economic models predict three land use decisions (CRP participation, crop choice and rotation, and conservation tillage adoption) at more than 44,000 National Resource Inventory sites in the Upper Mississippi River Basin under the four policies. The physical model then estimates the effect of land use decisions on NO_3-N concentrations in the Mississippi River.

Results from our first empirical application suggest that the fertilizer-use tax is much more cost-effective than the three conservation easement policies. Among the three conservation easement policies, payments for conservation tillage are most cost-effective but can reduce NO_3-N concentrations up to only 37 percent. The potential for incentive payments for corn-soybean rotations is even more limited. These payments also impose a higher cost to society than the payments for conservation tillage. The Conservation Reserve Program can be used to achieve the highest reduction in NO_3-N concentrations, but it also imposes the highest cost to the society among the four policies considered in this study. Results from our second empirical application show that the targeted fertilizer-use tax is much more cost-effective than the targeted tax for reducing NO_3-N loadings.

The 2002 Farm Bill represents a significant commitment of resources to conservation by reauthorizing and expanding the exiting conservation programs and by establishing new conservation programs. Some of these programs have been criticized as political payments. However, there was little empirical evidence that these programs are cost effective compared with other commonly suggested policy instruments for controlling nonpoint source pollution. Findings from this study suggest that a simple fertilizer-use tax is much more cost effective than several commonly suggested approaches for reducing nitrate water pollution within the Mississippi River Basin and for controlling hypoxia problem in the Gulf of Mexico. However, political difficulties of instituting such a tax cannot be prohibitive. Ultimately, policy makers must balance economic efficiency, equality and political feasibility when selecting policies for controlling nonpoint source pollution from agriculture.

Endnotes

[1] Although the Upper Mississippi River Basin also includes small parts of North and South Dakota, these areas are not included in this study.

[2] Conservation tillage refers to any tillage operation, which leaves at least 30 percent of crop residue after harvesting. Any tillage operation leaving less than 15 percent of crop residue is classified as conventional tillage.

[3] This type of logistic models have 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; Wu and Segerson; Hardie and Parks; Plantinga, Mauldin, and Miller), the choice of irrigation technologies (Caswell and Zilberman), and the choice of alternative crop management practices (Wu and Babcock, 1998).

[4] The main difference between the crop choice model used in this study and the one in Wu at al. (2004) is that here we include input prices such as nitrogen fertilizer prices and wage rate as independent variables rather than total production cost to facilitate the evaluation of nitrogen fertilizer use taxes.

[5] The 1997 NRI data used here contained crop information, but not tillage information.

[6] Both Anonymous (2004a) and (2004b) is available upon request.

[7] Our first integrated model compares the simulated NO_3-N concentrations with measured concentrations using annual average values, not monthly averages, to facilitate our region-scale SWAT analysis. Land management scenarios in our SWAT model assume that farmers apply fertilizer (anhydrous ammonia) in early spring only, whereas many farmers in the region apply fertilizers more than once as insurance for unexpected weather events. Thus, although the first model simulates annual average NO_3-N concentrations reasonably, it may not be true for monthly averages. The second integrated model overcomes this limitation.

[8] The Des Moines Watershed consists of 9 subbasins in figure 8. Those include subbasins 51, 52, 60, 65, 66, 69, 81, 103, and 104.

References

Anonymous. “Controlling Hypoxia in the Gulf of Mexico at its Sources: Easements or Taxes?” Submitted to *Land Economics*. 2004a.

Anonymous. “Targeted vs. Uniform Input-Use Taxes for Reducing Nitrate Water Pollution.” To be submitted to *Ecological Economics*. 2004b.

Antle, J.M., and S.M. Capalbo. “Econometric-Process Models for Integrated Assessment of Agricultural Production Systems.” *American Journal of Agricultural Economics* 83 (May 2001): 389-401.

Batie, S. and D. Ervin. “Flexible Incentives for Environmental Management in Agriculture: A Typology.” Paper presented at conference on “Flexible Incentives for the Adoption of Environmental Technologies in Agriculture.” Gainesville, FL, 1997.

Braden, J.B., G.V. Johnson, A. Bouzaher, and D. Miltz. “Optimal Spatial Management of Agricultural Pollution.” *American Journal of Agricultural Economics* 71 (May 1989): 404-13.

Cabe, R. and J. A. Herriges. “The Regulation of Non-Point-Source Pollution under Imperfect and Asymmetric Information.” *Journal of Environmental Economics and Management* 22 (March 1992): 134-46.

Caswell, M., and D. Zilberman. “The Choice of Irrigation Technologies in California.” *American Journal of Agricultural Economics* 67 (May 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): 529-38.

Claassen, R., and R. D. Horan. "Uniform and Non-Uniform Second-Best Input Taxes." Environmental and Resource Economics. 19(May 2001): 1-22.

Cooper, J.C., and R.W. Keim. “Incentive Payments to Encourage Farmer Adoption of Water Quality Protection Practices.” *American Journal of Agricultural Economics* 78 (February 1996): 54-64.

Denabaly, M. and H. Vroomen. “Dynamic Fertilizer Nutrient Demands for Corn: A Cointegrated and Error-Correcting System.” *American Journal of Agricultural Economics* 75 (February 1993): 203-9.

De Roo, H. C. “Nitrate Fluctuations in Ground Water as Influenced by Use of Fertilizer.” Connecticut Agricultural Experiment Station, New Haven, Bulletin 779, 1980.

Duffy, M. D. *Estimated Costs of Crop Production in Iowa - 2000*. Iowa State University Cooperative Extension Service, FM 1712, 2000.

Ervin, C.A. and D.E. Ervin. “Factors Affecting the Use of Soil Conservation Practices: Hypotheses, Evidence, Policy Implications.” *Land Economics* 58 (August 1982): 277-92.

Farm Service Agency. *Conservation Reserve Program Fact Sheet*. Washington D.C.: United States. Department of Agriculture, 2003.

Food and Agricultural Policy Research Institute. *U.S. Agricultural Outlook*. Iowa State University and the University of Missouri-Columbia, 1999.

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 (November 1995): 891-900.

Gilliam, J. W., and G. D. Hoyt. “Effect of Conservation Tillage on Fate and Transport of Nitrogen.” In *Effects of Conservation Tillage on Groundwater Quality*, eds. Lewis Publishers, Inc., Chelsea, Michigan, 1987, 217-40.

Goolsby, D. A. and W. A. Battaglin. “Sources and Transport of Nitrogen in the Mississippi River,” paper presented at the American Farm Bureau Federation Workshop “From the Corn Belt to the Gulf: Agriculture and Hypoxia in the Mississippi River Watershed.” St. Louis, MO, 1997.

Grady, S. J. “Statistical Comparison of Ground-Water Quality in Four Land-Use Areas of Stratified-Drift Aquifers in Connecticut.” U.S. Geological Survey Toxic Substances Hydrology Program-Proceedings of the Technical Meeting, Phoenix, Arizona, September 26-30, 1988. eds. G. E. Mallard and S. E. Ragone. Reston, Virginia: Water-Resources Investigations Report 88-4220. 1989.

Griffin, R. and D. W. Bromley. “Agricultural Runoff as a Nonpoint Externality.” *American Journal of Agricultural Economics* 64 (August 1982): 547-52.

Helfand, G. E. and B. W. House. “Regulating Nonpoint Source Pollution Under Heterogeneous Conditions,” *American Journal of Agricultural Economics* 77 (November 1995): 1024-32.

Hallberg, G.R. "Nitrate in Ground Water in the United StatesV." In *Nitrogen Management and Ground-Water Protection* R.F. Follet (ed.)., pp35-74. New York: Elsevier Science Publishing, 1989.

Helms, G.L., D.V. Bailey, T.F. Glover. "Government Programs and Adoption of Conservation Tillage Practices on Nonirrigated Wheat Farms." *American Journal of Agricultural Economics* 69 (November 1987): 786-95.

Hochman,E., and D. Zilberman. "Examination of Environmental Policies Using Production and Pollution Microparameter Distribution." *Econometrica* 46 (July 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 (November 1991): 1063-73.

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 (5 1983): 428-30.

Kurkalova, L., C. Kling., and J. Zhao. *Green Subsidies in Agriculture: Estimating the Adoption Costs of Conservation Tillage from Observed Behavior*. CARD Working Paper 01-WP-286. Ames: Center for Agricultural and Rural Development, 2003.

Mapp, H.P., D.J. Bernardo, G.J. Sabbagh, S.Geleta, and K.B. Watkins. "Economic and Environmental Impacts of Limiting Nitrogen Use to Protect Water Quality: A Stochastic Regional Analysis." *American Journal of Agricultural Economics* 76 (November 1994): 889-903.

Neitsch, S. L., J. G. Arnold, J. R. Kiniry, R. Srinivasan, and J. R. Williams. *Soil and Water Assessment Tool Theoretical Documentation Version 2000*. Temple: Blackland Research Center, 2002.

Pionke, H. B., and J. B. Urban. "Effect of Agricultural Land Use on Ground-Water Quality in Small Pennsylvania Watershed." *Ground Water* 23 (January/February 1985): 68-80.

Piper, S., W. –Y. Huang, and M. Ribaudo. "Farm Income and Ground Water Quality Implications From Reducing Surface Water Sediment Deliveries." *Water Resources Bulletin* 25 (December 1989): 1217-30.

Segerson, K. "Uncertainty and Incentives for Nonpoint Pollution Control." *Journal of Environmental Economics and Management* 15 (March 1988): 87-98.

Shortle, James and James Dunn. "The Relative Efficiency of Agricultural Source Water Pollution Control Policies." *American Journal of Agricultural Economics* 68 (August 1986): 668-77.

Stecker, J. A., D. D. Buchholz, R. G. Hanson, N. C. Wollenhaupt, and K. A. McVay. "Tillage and Rotation Effects on Corn Yield Response to Fertilizer Nitrogen on Aqualf Soils." *Agronomy Journal* 87 (May/June 1995): 409-15.

Taylor, M. L., R. M. Adams, and S. F. Miller. "Farm-Level Response to Agricultural Effluent Control Strategies: The Case of the Willamette Valley." *Journal of Agricultural and Resource Economics* 17 (July 1992):173-85.

United States Department of Agriculture, National Agricultural Statistics Service. *Agricultural Statistics 2000*. Washington D.C., 2001.

United States Environmental Protection Agency, Office of Water. *2000 National Water Quality Inventory*. Washington D.C., 2002.

Williams, J.R., R.V. Llewelyn, and G.A. Barnaby. "Risk Analysis of Tillage Alternatives with Government Programs." *American Journal of Agricultural Economics* 72 (February 1990): 172-91.

Wu, J. and B. A. Babcock. "Contract Design for the Purchase of Environmental Goods from Agriculture" *American Journal of Agricultural Economics* 78 (November 1996): 935-45.

Wu, J., and B. A. Babcock. "Metamodeling Potential Nitrate Water Pollution in the Central United States." *Journal of Environmental Quality* 28 (November/December 1999): 1916-28.

Wu, J., R. M. Adams, C. L. Kling, and K. Tanaka. "From Micro-Level Decisions to Landscape Changes: An Assessment of Agricultural Conservation Policies." *American Journal of Agricultural Economics* 86 (February 2004): 26-41.

Xepapadeas, A. P. "Environmental Policy Design and Dynamic Nonpoint-Source Pollution," *Journal of Environmental Economics and Management* 23 (July 1992): 22-39.

Yiridoe, E. K. and A. Weersink. "Marginal Abatement Costs of Reducing Groundwater-N Pollution with Intensive and Extensive Farm Management Choices." *Agricultural and Resource Economics Review* 27 (October 1998): 169-85.