AN ABSTRACT OF THE THESIS OF

Katsuya Tanaka for the degree of Doctor of Philosophy in Agricultural and Resource Economics presented on December 2, 2003.
Title: Essays on Conservation Policies and Agricultural Nonpoint Source Pollution Control.

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This dissertation consists of three papers on agricultural nonpoint source pollution and control. The first paper focuses primarily on agricultural land use changes under alternative conservation policies. The second and third papers address environmental implications of these policies and their cost effectiveness.

In the first paper, the effect of alternative conservation policies on agricultural land use in the Upper Mississippi River Basin is quantitatively evaluated. Site-specific land use decisions are analyzed using a set of discrete choice models and site-specific economic and physical information. The models are then used to predict farmers' choice of crop, crop rotation, and participation in the Conservation Reserve Program under alternative conservation policies. Results suggest that acreage planted to "polluting" crops (corn and soybean) are quite responsive to the fertilizer-use tax, but not quite as responsive to the two payment programs considered in this paper.

In the second paper, the social costs of alternative conservation policies are estimated for reducing nitrate-N concentrations in the Upper Mississippi River. This objective is achieved by developing an integrated modeling framework consisting of economic and physical models. Results suggest that the nitrogen fertilizer-use tax is much more cost effective than the three payment programs. Incentive payments for conservation tillage are most cost effective among the three payment programs, but can only reduce nitrate-N concentrations to a limited level. The potential of incentive payments for corn-soybean rotation is even more limited. Although the Conservation

Reserve Program can achieve the highest level of nitrate-N concentrations reduction, it imposes the highest cost to society.

In the third paper, the relative efficiency between the targeted and uniform fertilizer-use taxes for reducing agricultural water pollution is estimated. This paper adds some refinements to the integrated model developed in the second paper, for assessing nitrate-N runoff from the 9 subbasins in the Des Moines Watershed. In contrast to previous studies, results in this paper suggest that the targeted fertilizer-use tax outperforms the uniform tax under spatially heterogeneous conditions. The targeted fertilizer-use tax reduces the aggregate farm profit loss under the uniform tax by up to 30 percent in this watershed.

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Essays on Conservation Policies and Agricultural Nonpoint Source Pollution Control

by
Katsuya Tanaka

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

Presented December 2, 2003
Commencement June 2004

Doctor of Philosophy thesis of Katsuya Tanaka presented on December 2, 2003.

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Katsuya Tanaka, Author

ACKNOWLEDGMENTS

I have been fortunate to have a number of excellent people who have assisted immensely my degree, and without whom this dissertation would have not been possible.

I wish to express my warmest gratitude to my major professor and advisor , Dr. JunJie Wu. All of his comments, suggestions, support and encouragement, personal and academic, have left a mark on this work.

I would like to thank thesis committee, Dr. Richard M. Adams, Dr. William G. Boggess, Dr. Gregory M. Perry, and Dr. Steven H. Strauss. Their valuable and thoughtful comments and suggestions in the oral preliminary examination provided means to improve this dissertation.

I am also grateful to Mr. Jerrome Neppel at Soil and Water Conservation Society. The physical model developed in this dissertation owes largely his knowledge and experience.

Lastly, I wish to thank my parents for continuous and loving support throughout my life. My gratitude to them is beyond words.

CONTRIBUTION OF AUTHORS

Dr. JunJie Wu was involved in the design, analysis, and writing of each manuscript. Dr. Wu also assisted with data collection for each manuscript. Mr. Jerrome G. Neppel assisted with SWAT model development in chapter 3.

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LIST OF ACRONYMS

Acronym	
ARS	Agricultural Research Service
CBT	Chicago Board of Trade
CRP	Conservation Reserve Program
CS	Conservation Tillage
CT	Conventional Tillage
DEM	Digital Elevation Model
EPA	Environmental Protection Agency
FSA	Farm Service Agency
HRU	Hydrologic Response Unit
HUC	Hydrologic Unit Code
LULC	Land Use and Land Cover spatial map
MLC	Maximum Contaminant Level
MRB	Mississippi River Basin
NASS	National Agricultural Statistic Service
NLCD	National Land Cover Data
NO_3-N	Nitrate-Nitrogen
NPS	Nonpoint Source pollution
NRCS	Natural Resource Conservation Service
NRI	Natural Resource Inventory
NT	No-Till
STATSGO	State Soil Geographic digital soil association map
SWAT	Soil and Water Assessment Tool
USDA	United States Department of Agriculture
USGS	United States Geological Survey

ESSAYS ON CONSERVATION POLICIES AND AGRICULTURAL NONPOINT SOURCE POLLUTION CONTROL

CHAPTER 1

GENERAL INTRODUCTION

Katsuya Tanaka

Modern U.S. agriculture has been identified as a leading source of nonpoint source (NPS) pollution as a result of its productive but chemical-intensive crop management practices. For example, the most recent national water quality inventory reports that runoff from agriculture is the largest source of water quality problems in the surveyed rivers and streams. The inventory also reports that agricultural nutrients, such as nitrate-N (NO_3-N) are the third largest pollutants in the surveyed waters (Office of Water 2002). One of the most visible impacts of agricultural NPS pollution can be seen in the Northern Gulf of Mexico, where one of the world's largest hypoxic water has been identified since 1970's. This hypoxic water condition has been formed due mainly to significant nitrogen loads from the Mississippi River.

The Farm Security and Rural Investment Act of 2002 (Farm Bill) represents the largest commitment of resources to conservation on private lands. Specifically, the 2002 Farm Bill places a strong emphasis on voluntary conservation on private farmland through incentive payments such as cost-share, rental payments, and technical assistance. To this end, the Bill establishes and reauthorizes a number of programs providing incentive payments to farmers who adopt conservation practices on their land (e.g. Conservation Reserve Program, Environmental Quality Incentive Program, and Conservation Security Program). However, there is little evidence that that these payment programs are cost effective compared with other commonly suggested policy instruments for controlling NPS pollution such as chemical input-use taxes. The primary objectives of this dissertation are to: (a) evaluate quantitatively the effects of conservation policies on agricultural land use; (b) estimate the social costs of conservation policies; and (c) estimate the relative efficiency of targeted and uniform input-use taxes for reducing agricultural nitrate water pollution.

The first paper (chapter 2), *Evaluating the Effect of Conservation Policies on Agricultural Land Use: A Site-Specific Modeling Approach*, evaluates quantitatively the effect of three conservation policies (nitrogen fertilizer-use tax, incentive payments for corn-soybean rotation, and the Conservation Reserve Program) on agricultural land use in the Upper Mississippi River Basin. Site-specific land use decisions are estimated using a set of discrete choice models and data from the 1982, 1987, 1992, and 1997 Natural Resource Inventories. The models are then used to predict farmers' choice of crop, crop rotation, and participation in the Conservation Reserve Program at more than 48,000 NRI sites under the three policy scenarios. Results suggest that acreage planted to "polluting" crops (corn and soybean) are quite responsive to the fertilizer-use tax, but not as responsive to the incentive payments for corn-soybean rotation and Conservation Reserve Program. Agricultural land use changes under the alternative policies simulated in this paper, serve as one of the primary inputs for the empirical analyses in the following two papers which assess the cost effectiveness and environmental implications under alternative polices.

The second paper (chapter 3), *Reducing Nitrogen Loads to Control Hypoxia in the Gulf of Mexico: Easements or Taxes?* estimates the social cost of alternative conservation policies to control agricultural NPS pollution. More specifically, this paper evaluates the social costs of: (1) nitrogen fertilizer-use taxes; (2) incentive payments for conservation tillage; (3) incentive payments for corn-soybean rotations; and (4) the

Conservation Reserve Program to reduce NO_3-N concentrations in the Upper Mississippi River. This objective is achieved by developing an integrated modeling framework consisting of economic and physical models. The economic models, which are based on the first paper, predict farmers' crop rotation, tillage practices, and participation in the Conservation Reserve Program at more than 44,000 Natural Resource Inventories sites in the Upper Mississippi River Basin. The estimated land use changes under the four policies are incorporated into the Soil and Water Assessment Tool to assess NO_3-N concentrations in the Upper Mississippi River. Results suggest that the nitrogen fertilizer-use tax is much more cost effective than the three payment programs. Incentive payments for conservation tillage practices are most cost effective among payment programs, but can only reduce NO_3-N concentrations to a limited level. The potential of incentive payments for corn-soybean rotation for reducing NO_3-N concentrations is even more limited. They also impose a higher cost to society than payments for conservation tillage. Results also suggest that the Conservation Reserve Program can achieve the highest level of NO_3-N concentrations reduction, but imposes the highest cost to society among policies considered in this paper.

The third paper (chapter 4), *Targeted vs. Uniform Input-Use Taxes for Reducing Nitrate Water Pollution*, builds on the second paper, which concludes that the nitrogen fertilizer-use tax is much more cost effective than conservation payment programs. However, this paper only examines the cost effectiveness of uniform taxes. Targeted, or non-uniform taxes may outperform the uniform taxes if there exists a large variation in the marginal costs of pollution control. The third paper estimates the relative efficiency of targeted and uniform fertilizer-use taxes for reducing agricultural NPS pollution. This study also improves the integrated model by using better physical information to assess the level of NO_3-N runoff from the 9 subbasins in the Des Moines Watershed, Iowa. In contrast to some previous studies, results in this paper suggest that the targeted tax outperforms the uniform tax significantly. The targeted fertilizer-use tax reduces the aggregate farm profit loss under the uniform tax by up to 30 percent in this watershed, depending on the environmental standards.

CHAPTER 2

EVALUATING THE EFFECT OF CONSERVATION POLICIES ON AGRICULTURAL LAND USE: A SITE-SPECIFIC MODELING APPROACH

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Revised and to be resubmitted to *Canadian Journal of Agricultural Economics.*

ABSTRACT

This study evaluates quantitatively the effects of three conservation policies (payments for cropland retirement, chemical-use taxes, and payments for crop rotations) on agricultural land use in the Upper Mississippi River Basin. This objective is achieved by estimating two logit models of land use decisions using data from the 1982, 1987, 1992, and 1997 Natural Resource Inventories. The models are then used to predict farmers' choice of crop, crop rotation, and participation in the Conservation Reserve Program (CRP) at more than 48,000 Natural Resource Inventories sites under the policies. Results suggest that an increase in the CRP rental rates significantly increases the CRP acreage, but most of the acreage increase comes from "non-polluting" crops. In contrast, the fertilizer-use tax significantly reduces the polluting crop acreages, and thus is likely to reduce agricultural chemical use and pollution. Although the incentive payments for corn-soybean rotation converts land from continuous corn to corn-soybean rotation, these acreage responses are quite inelastic.

INTRODUCTION

Since the first Clean Water Quality Act was passed in 1972, the United States has made significant efforts to control water pollution, mostly by regulating pollution from point sources such as industries and sewage treatment plants[1]. As a result, water pollution from point sources has been significantly reduced. However, pollution from diffuse, or nonpoint sources was not controlled until the 1987 amendments to the Water Quality Act[2]. Since then, particularly in the last decade, considerable amount of efforts has been made to control nonpoint source (NPS) pollution, but NPS pollution remains the largest source of water quality problems in the U.S. today. One of the most visible impacts of agricultural NPS pollution can be seen in the Gulf of Mexico. The delivery of chemicals, mainly nitrate-nitrogen (NO_3-N), through the Mississippi River to the Gulf contributes to one of the largest hypoxic zones in the world[3].

Modern U.S. agriculture has been recognized as a significant source of NPS pollution due to its productive but chemical intensive management. The 2000 National Water Quality Inventory reports that agricultural production activities are the leading sources of water quality problems in the surveyed rivers and streams. The inventory also reports that agricultural nutrients are the third largest pollutant in the surveyed waters (Office of Water 2002). Although U.S. agriculture has been well known for its high productivity, it usually involves intensive fertilizer applications such as anhydrous ammonia. As a result, NO_3-N transported from agricultural land into surface and ground waters has led to ecological and human health concerns. In addition, NO_3-N runoff and leaching represent economic loss to farmers as well as to water consumers who must pay for NO_3-N removal from drinking water.

As is the case with most types of NPS pollution, agricultural NPS pollution relates directly to the way in which land is used. In other words, not all cropland contributes equal amounts of water pollution. The level of pollution depends critically on chemical input use and farming practices. For example, producing row crops such as corn requires intensive fertilizer application for their growth. In contrast, producing other crops such as alfalfa requires less or no fertilizer application. Thus, producing row crops generally results in higher level of chemical loss and pollution than other crops. The level of pollution also depends on crop rotations. Although continuous corn production is one of the common farming practices, it usually involves intensive fertilizer application and thus results in significant nutrient loss. Corn-soybean rotation reduces the level of fertilizer use because fertilizer is not usually applied when soybean is planted. In addition, soybean leaves nitrogen in the soil through legume nitrogen fixation.

Conservation policies affecting those farmers' decisions may affect farmers' land use decisions and resulting level of water pollution. The Conservation Reserve Program (CRP), administrated by the Farm Service Agency (FSA), is a voluntary land retirement program for agricultural landowners. The CRP was originally enacted in 1985, and remains the largest easement program in the U.S. Through CRP, agricultural landowners receive annual rental payments and cost-share assistance to establish resource-conserving cover (Natural Resource Conservation Service 2003). The primary objectives of the CRP are to: (1) reduce soil erosion and sedimentation in streams and lakes; (2) establish wildlife habitat and enhance forest and wetland resources; (3) protect the Nation's ability to produce food and fiber. Thus, highly erodible cropland and other environmentally sensitive lands are encouraged to adopt the program. If more cropland is retired through this program, the level of agricultural water pollution may decline.

Other conservation policies may induce farmers to adopt conservation practices and thus reduce water pollution. For example, the incentive payments for corn-soybean rotation may be an effective instrument. Under this policy, per-acre payments are offered for farmers who adopt corn after soybean, or soybean after corn. Although continuous corn is still a major cropping practice in the U.S. agriculture, properly designed incentive payments may induce farmers to convert continuous corn to corn-soybean rotation. Alternatively, the tax may be imposed on the use of pollutants. For example, the chemical fertilizer-use tax may reduce farmers' fertilizer applications in two ways. First, the tax will reduce farmers' fertilizer application rates (policy impact at the intensive margin). Second, farmers will change their cropping patterns (policy impact at the extensive margin) because fertilizer-requiring crops, such as corn, are relatively less profitable under the tax. These changes in turn affect the aggregate fertilizer use and water pollution.

The primary objective of this paper is to develop econometric models to evaluate the effect of alternative conservation policies on agricultural land use in the Upper Mississippi River Basin (MRB), a region under increasing scrutiny as a significant source of nutrient loadings to the Mississippi River, causing hypoxia in the Gulf of Mexico. To achieve this objective, we first estimate econometric models to evaluate the effect of various economic and physical variables on farmers' land use decisions. Then we use the models to simulate the impact of conservation policies (the Conservation Reserve Program, incentive payment for corn-soybean rotation practice, and chemical-use tax) on land use in the basin.

Much research has focused on the effect of government policies on agricultural land use (Lidman and Bawden 1974; Chavas et al 1983; Chavas and Holt 1990; Chembezi and Womack 1992; Wu and Brorsen 1995; Wu and Segerson 1995; Claassen and Tegene 1999; Wu and Adams 2001; Kurkalova et al 2003). For example, Chavas and Holt (1990) analyze multiple acreage decisions under uncertainty in the U.S. In particular, they evaluate corn and soybean acreage responses under alternative support price levels. However, they do not include physical attributes such as land quality. Chembezi and Womack (1992) apply the region-scale acreage response models to assess the impact of farm program on acreage response for corn in the Corn Belt and Lake States, and for wheat in the Lake States. The empirical model of this study ignores not only risks associated with crop production but also physical attributes. Wu and Brorsen (1995) develop acreage response equations for nine major crops of Wisconsin. Using estimated equations, they evaluate the impacts of three government policies (reduction in the target price for corn; increase in the Acreage Reduction Program rate for corn, and increase in chemical price) on cropping patterns in the region. Claassen and Tegene (1999) analyze land use choices between crop production and CRP participation in the Corn Belt. They use the discrete choice model and site-specific information for predicting farmers' land retirement decisions. However, their model do not predict choice among crop production (e.g. corn, soybean, or hay). Wu and Adams (2001) evaluate the relationship between production risks, cropping patterns, and revenue insurance program in the Corn Belt. The most recent studies in this field include Kurkalova et al (2003). They estimate the effect of incentive payments for conservation tillage on farmers' adoption decisions. Overall, none of these studies has compared the effect of land retirement policy such as a CRP with the effect of alternative policies for conservation practice. This study compares the three different conservation policies, including the CRP, incentive payments for corn-soybean rotation, and conventional chemical input-use tax for inducing farmers to adopt conservation practices.

This paper is organized as follows. The next section describes the empirical models to be estimated in this study. The third sections presents the study region, data and their sources, and estimation results. The fourth section illustrates the simulated agricultural land use changes under alternative conservation policies. The last section summarizes and concludes this study.

THE LOGIT MODEL

Suppose a risk-neutral farmer, labeled *i*, faces a choice among *J* agricultural management alternatives (e.g. type of crop to produce, and whether or not to participate in the CRP). Each alternative yields a different level of utility, and the utility that farmer *i* can obtain from alternative *j* is denoted by U_{ij}, where $j = 1,...,J$. Note that this utility is known to the farmer, but not to the researcher because not all variables affecting farmer's utility is observable. Farmer *i* will choose alternative *j* if and only if $U_{ij} \geq U_{ik}$, for all $k \neq j$. Although the researcher cannot observe the farmer's utility, he/she can observe two types of attributes that affect farmer *i*'s utility. The first type of attributes is the observed characteristics of alternatives faced by farmer *i*, denoted by z_{ij}. Those attributes include revenue and costs of alternative crops. The second type of attributes is the observed characteristics of farmer *i*, denoted by y_i. Those include cropping history, land quality, and climatic conditions. By observing these attributes, the researcher can specify a function that relates to farmer *i*'s utility from each alternative. This function is often called the "representative utility", denoted by $V_{ij} = V(z_{ij}, y_i, \beta_j^{'})$, where $\beta_j^{'}$ is a vector of parameters to be estimated. Based on the representative utility, we can decompose farmer *i*'s utility by $U_{ij} = V_{ij} + \varepsilon_{ij}$, where ε_{ij} represents the factors affecting farmer *i*'s utility from choosing alternative *j*. Note that ε_{ij} s are not observable by the researcher, and are therefore treated as a random error term. Following McFadden (1974), the probability that farmer *i* chooses alternative *j* is

$$
\begin{aligned}
P_{ij} &= \Pr\left(V_{ij} + \varepsilon_{ij} > V_{ik} + \varepsilon_{ik} \quad \forall\, j \neq k\right) \\
&= \Pr\left(\varepsilon_{ik} < \varepsilon_{ij} + V_{ij} - V_{ik} \quad \forall\, j \neq k\right) \qquad (1)
\end{aligned}
$$

Under the assumption that ε's are independently and identically distributed with the type I extreme value distribution[4], the probability takes the multinomial logit model:

$$
P_{ij} = \frac{\exp\left(\beta_j^{'} x_{ij}\right)}{\sum_J \exp\left(\beta_j^{'} x_{ij}\right)}, \quad j = 1,2,\ldots,J \qquad (2)
$$

where $x_{ij} \equiv (z_{ij}, y_i)$ is a vector of independent variables that affect farmers *i*'s utility. The logit model has two desirable properties. First, the predicted probability P_{ij} is always between zero and one. Second, the probability increases when representative utility V_{ij} increases, reflecting an improvement in the observed attribute while other utilities held constant. The probability approaches to one as V_{ij} approaches ∞. Similarly, the probability decreases when V_{ij} decreases, and approaches to zero as V_{ij} approaches $-\infty$. However, the probability cannot be exactly zero or one.

Because the logit model is nonlinear, the estimated coefficients are difficult to interpret. The most commonly used method of interpretation is the marginal effect. Taking the derivative of equation (2) with respect to the one of independent variables, we have

$$\frac{\partial P_{ij}}{\partial x_j} = P_{ij}\left(\beta_{jx} - \sum_j P_{ij}\beta_{jx}\right) \tag{3}$$

where β_{jx} is the coefficient of variable x_j. The marginal effect does not need to have the same sign as the corresponding coefficient because it depends on all the coefficients of x_j.

Alternatively, the estimated coefficients can be measured by the elasticity of probability, indicating the percent change in the probability of alternative associated with one percent increase in the independent variable. The elasticity of crop *j*'s probability with respect to independent variable x_j is given by

$$\frac{\partial P_{ij}}{\partial x_j}\frac{x_j}{P_{ij}} = x_j\left(\beta_{jx} - \sum_j P_{ij}\beta_{jx}\right) \qquad (4)$$

This may be preferred method of interpretation, because elasticities are normalized for the variables' units. As is the case with the marginal effect, the sign of elasticity does not need to be the same as the corresponding coefficient because it depends on both sign and magnitude of all coefficients on x_j.

To estimate agricultural land use changes under conservation policies, the two logit models are used in the following order. First, the CRP model is used to predict which sites participate in the CRP. Second, the crop choice model is applied to the sites not enrolling in the CRP. The crop choice model assigns one of major crops (corn, soybean, hay, and other crop) for each of NRI sites in the region.

THE APPLICATION TO THE UPPER MISSISSIPPI RIVER BASIN

Study Region

The empirical analysis is conducted in the Upper Mississippi River Basin[5] (MRB). The Upper MRB consists of the drainage of the MRB above the confluence with the Ohio River, excluding the Missouri River Basin. The Upper MRB encompasses more than 480,000 square kilometers in six states: Illinois, Indiana, Iowa, Missouri, Minnesota, and Wisconsin (Figure 2.1). The climate of the basin is subhumid continental and the average monthly maximum temperature ranges from -9.8 degrees C° in January in Central Minnesota, to 31.7 degrees C° in July in Central Missouri. The average annual precipitation increases from 575 millimeters in the Western part of Minnesota, to 981 millimeters in the Central part of Illinois. About 75 percent of the annual precipitation falls during corn growing season, from April to October. Soil type ranges from heavy, poorly drained clay soil to light, well-drained sands. In the most parts of the basin, agriculture is the dominant land use.

The Upper MRB comprises about 15 percent of the drainage area of the entire MRB but contributes more than 50 percent of the nitrate discharged to northern Gulf of Mexico (Goolsby et al 1997). This is mostly due to chemical-intensive agricultural operation in the upper basin. According to the 1997 Natural Resource Inventory (NRI), more than 40 percent of land in the basin is used for agricultural production (Table 2.1). Corn, soybean, and hay are the major crops in the basin, accounting for 72 percent of total cropland in the basin. Two major cropping systems are corn-soybean rotation and continuous corn, accounting for 11 percent and 49 percent of cropland in the basin. Among tillage operations, conventional tillage is the most widely operated practice, accounting for 75 percent of cropland. Conservation tillage accounts for only 25 percent of cropland, but has been gaining more attention. About 3 percent of cropland in this basin is enrolled in the Conservation Reserve Program. Most of the CRP land is used to plant grasses and legumes.

Figure 2.1 The Upper Mississippi River Basin

Table 2.1 The Number of NRI Sites in the Upper Mississippi River Basin

	All land		Agricultural land		CRP land	
State	Sites	Acres	Sites	Acres	Sites	Acres
Illinois	29,592	28,913,000	14,285	21,292,800	389	500,500
Indiana	2,215	1,947,700	1,136	1,505,400	10	10,400
Iowa	23,498	24,932,600	11,645	19,700,200	843	1,138,000
Minnesota	27,481	30,362,500	10,277	17,040,800	579	714,300
Missouri	9,043	9,448,100	3,089	4,883,800	319	420,700
Wisconsin	20,911	24,857,100	5,359	9,926,400	353	531,800
Total	112,740	120,461,000	45,791	74,349,400	2,493	3,315,700

Data and Data Sources

To capture economic and physical factors affecting farmers' land use decisions for the CRP and crop choice decisions, this study collects the three types of data. Those include: (1) site-specific land use and land characteristics; (2) expected revenue, input prices, and CRP rental rates; and (3) climatic conditions. Below we describe details in each data and their sources.

Site-Specific Land Use and Land Characteristics

A primary data source for the CRP and crop choice models is the Natural Resource Inventory (NRI), conducted by the Natural Resource Conservation Service (NRCS). The NRI is scientifically based, longitudinal panel survey of the Nation's soil, water, and related resources, designed to assess conditions and trends every five years. The NRI sample design is based on a stratified two-stage area sample of the U.S. non-federal lands[6] The 1997 NRI contains more than 800,000 sites in 48 conterminous States, Hawaii, Puerto Rico, and the U.S. Virgin Islands.
Table 2.1 shows that the Upper Mississippi River Basin includes the total of 112,740 sites and that 48,284 sites are used for agriculture and CRP.

Each NRI contains information on 4-year cropping history (the survey year and previous three years) at each site. Thus, by pooling the 1997 NRI and previous three NRIs, we have the site-specific land use and crop choice information for 16 years. Because information on CRP participation is available only in the 1992 and 1997 NRIs, the CRP model is estimated using these two NRIs. Each NRI site is assigned a weight, called the expansion factor, which indicates the acreage the site represents. For example, we can calculate the total CRP acreage in the region by summing expansion factors for all sites participated in the CRP.

Each NRI also contains the site-specific information about physical characteristics. To capture the difference in land productivity across sites, the CRP and crop choice models include the variables reflecting physical characteristics at each site.

More specifically, we obtain land capacity class, land slope percent, and erodibility index for wind and water erosion from the 1997 NRI. A dummy variable for good quality land is constructed from land capacity class, defined as the land with a capacity class of 1 or 2[7]. Similarly, a dummy variable for medium quality land is created with a capacity class of 3 or 4. More detailed physical characteristics at each site are obtained from the SOIL5 database developed by the NRCS. The SOIL5 is linked to each site in the NRIs, we obtain site-specific physical attributes through the database. The variables from the SOIL5 include the maximum and minimum values of water capacity, organic matter percentage, soil pH, and soil permeability. To facilitate the estimations, we assume that the physical characteristics are constant within each county. Thus, the average values of physical attributes are calculated for each county. Because the physical characteristics generally change little over time, the values of physical characteristics obtained from the 1997 NRI and SOIL5 are assumed to represent an entire estimation period of 1982-1997.

Expected Revenue, Input Prices, and CRP Rental Rates

The expected revenue for corn during the estimation period is estimated using the expected price and yield for corn and their standard deviations. More specifically, the expected corn revenue in period *t*, $E(R_t)$, is estimated from the following equation:

$$E(R_t) = E(p_t)E(y_t) + \rho(p, y)\mathrm{sd}(p_t)\mathrm{sd}(y_t) \tag{5}$$

where $E(p_t)$ is the expected corn price, $E(y_t)$ is the expected corn yield, and $\mathrm{sd}(p_t)$ and $\mathrm{sd}(y_t)$ represent standard deviation of corn price and corn yield, respectively. ρ is the correlation coefficient between output price and yields, which is assumed to be constant over the estimation period. The expected corn 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. This average futures price is used as an approximation for the expected corn price. 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

$$\mathrm{sd}(p_t) = \left[\sum_{j=1}^{3} \omega_j \left(p_{t-j} - E_{t-j-1}(p_{t-j}) \right)^2 \right]^{0.5} \tag{6}$$

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). The CRP annual rental payments are obtained from the FSA. The CRP payments consist of annual rental payments, two types of one-time incentive payments, and cost-share assistance. This study uses the county average of annual rental payments for the period of 1990 to 2000. The data reports that the rental payment rates range from $15.40 to $112.60 per acre in the Upper MRB with an average of $78.30 per acre. Other variables reflecting farmers' production costs, including the annual average corn market price, wage rate, and fertilizer prices are obtained from the NASS Agricultural Statistics. 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.

Climatic Conditions

The variables representing climatic conditions are obtained from the Midwestern Regional Climate Center. Using historical weather information from the nearest weather station for the period of 1974-1994, we estimate the county-specific average of mean and standard deviation of maximum daily temperatures, and the mean precipitation during corn growing season. Because long-term average of climatic conditions change little over time, farmers' perceptions of the climatic conditions are assumed to be constant. Thus, the estimated 21-year average values of climatic conditions represent an entire estimation period.

To make the estimations computationally feasible, 10 percent of the NRI sites in the region is randomly selected. The descriptive statistics of independent variables, both in sample and out sample, are presented in table 2.2.

Table 2.2 Descriptive Statistics of Independent Variables for the Logit Models

	In-sample		Out-sample	
	Mean	St. deviation	Mean	St. deviation
CRP Rental Rate	0.83	0.17	0.83	0.17
Expected corn revenue	3.50	0.54	3.50	0.54
Variance of Corn Yield	473.02	150.12	473.60	151.22
Mean of max. temperature during corn growing season	78.22	3.18	78.25	3.18
St. deviation of max. temperature during corn growing season	9.55	0.83	9.55	0.83
Mean of max. precipitation during corn growing season	0.12	0.01	0.12	0.01
Fertilizer price	4.24	0.22	4.24	0.22
Wage rate	42.63	1.16	42.64	1.16
Land slope	4.22	4.84	4.17	4.79
Erodibility index water	6.50	12.79	6.47	12.66
Erodibility index wind	0.53	0.94	0.53	0.95
Average water capacity	0.18	0.04	0.18	0.04
% average organic matter	2.93	7.33	2.93	7.32
Average soil pH	6.54	0.63	6.54	0.63
Average soil permeability	2.02	2.55	1.98	2.50

The Estimation Results

Table 2.3 presents the estimated coefficients for the CRP model. Overall, the model fits the data plausibly well. Most coefficients are statistically significant at the 1 percent level. In addition, the model predicts correctly actual CRP participation at 95 percent in the region. Table 2.3 also presents the estimated elasticities of probabilities of the CRP participation with respect to the independent variables. All elasticities except those with respect to climatic variables are statistically significant at the 1 percent level. Results indicate that the CRP participation decisions are highly responsive to the CRP rental rate, cropping history, and wage rate. More specifically, a 1 percent increase in the CRP rental rate increases the probability of CRP participation by more than 2 percent. This suggests that policies affecting the CRP rental rates have significant impact on farmers' decisions to participate in the program. Similarly, a 1 percent increase in wage rate increases probability of CRP enrollment by 5 percent. This may reflect that an increase in wage rate reduces farmers' profits from farming operations, which in turn makes the CRP more attractive to farmers. Table 2.3 indicates that the elasticities with respect to the two erodibility indexes are positive. These elasticities are consistent with the fact that the CRP is intended to conserve highly erodible cropland. Table 2.3 also indicates that the elasticities with respect to the variance of corn yield is positive. This implies that farmers are more likely to retire from agricultural production when perceived production risks are high.

Table 2.3 Estimated Coefficients and Elasticities for the CRP Model

Variable	Coefficient	St. Error	Elasticity	St. Error
Constant	-11.328***	1.407		
CRP Rental Rate	2.539***	0.263	2.014***	0.209
Land used for corn production in previous growing season	-5.597***	0.275	-2.017***	0.099
Land used for soybean production in previous growing season	-6.621***	0.578	-1.594***	0.139
Land used for hay production in previous growing season	-8.626***	0.915	-0.668***	0.071
Variance of Corn Yield	0.001***	0.000	0.426***	0.102
St. deviation of max. temperature during corn growing season	0.050	0.048	0.447	0.442
Mean of max. precipitation during corn growing season	3.626	2.736	0.424	0.320
Wage rate	0.123***	0.028	5.000***	1.156
Medium quality land (NRCS land classes 3 and 4)	0.519***	0.067	0.168***	0.022
Erodibility index water	0.051***	0.002	0.316***	0.014
Erodibility index wind	0.552***	0.038	0.280***	0.019
Dummy variable for Indiana	-1.296***	0.476		
Dummy variable for Iowa	0.371***	0.114		
Dummy variable for Minnesota	0.447***	0.140		
Dummy variable for Missouri	0.478***	0.140		
Dummy variable for Wisconsin	0.311**	0.142		
R-square		0.31		
Fraction of Correct Predictions		0.95		

Note: One, two, and three stars indicate statistical significance at the 10%, 5% and 1% levels respectively.

Table 2.4 illustrates the estimated coefficients for the crop choice model. Because the expected revenues for corn and soybean are highly correlated, only the expected corn revenue is included in the model. The expected revenue for hay is not included because it is not statistically significant even at 10 percent level in the choice of any crop. This may imply that the revenue for hay does not affect farmers' crop choice decisions. Overall, the model fits the data reasonably. Most coefficients are significant at either 1 or 5 percent levels. In addition, the model correctly predicts actual crop choice at 65 percent of sites in the region. The expected revenue for corn, one of the primary variables for the policy analysis, is significant at the 1 percent level in each of the equations. This indicates that corn price affects the choice of not only own crop but also alternative crops through substitution effect. The price of fertilizer, another variable relevant for the policy analysis, is statistically significant in the choice of corn and soybean at the 1 percent level, but is not significant in the choice of hay. This is consistent with the agronomy information that hay does not usually require much nitrogen application.

Table 2.4 Estimated Coefficients for the Crop Choice Model

Variable	Corn Coeff.	Corn St. error	Soybean Coeff.	Soybean St. error	Hay Coeff.	Hay St. error
Constant	0.582	0.982	-18.252***	1.200	1.165	1.268
Expected corn revenue	0.370***	0.027	0.580***	0.031	0.109***	0.038
Land used for corn production in previous growing season	3.549***	0.042	4.331***	0.049	0.607***	0.070
Land used for soybean production in previous growing season	3.768***	0.044	1.998***	0.054	-0.352***	0.112
Land used for hay production in previous growing season	3.943***	0.086	2.645***	0.117	5.235***	0.082
Variance of Corn Yield	-0.0003**	0.000	0.001***	0.000	-0.0005***	0.000
Mean of max. temperature during corn growing season	-0.039***	0.008	0.093***	0.010	-0.047***	0.009
St. deviation of max. temperature during corn growing season	-0.104***	0.027	0.100***	0.031	-0.110***	0.035
Mean of max. precipitation during corn growing season	1.369	1.258	11.790***	1.414	3.747**	1.852
Land slope	-0.071***	0.004	-0.158***	0.006	-0.028***	0.005
Fertilizer price	-0.368***	0.072	-0.290***	0.079	0.094	0.102
Wage rate	0.027***	0.008	0.123***	0.010	0.030**	0.012
Good quality land (NRCS land classes 1 and 2)	0.304***	0.038	0.389***	0.043	0.260***	0.055
Average water capacity	2.946***	0.665	-4.241***	0.768	1.592*	0.908
% average organic matter	-0.017***	0.003	-0.005	0.003	-0.019***	0.004
Average soil pH	0.084***	0.030	0.223***	0.034	-0.199***	0.043
Average soil permeability	0.008	0.009	-0.076***	0.010	-0.007	0.012
Dummy variable for IN	0.210*	0.122	-0.001	0.132	-0.170	0.235
Dummy variable for IA	-0.044	0.051	-0.254***	0.057	0.232***	0.078
Dummy variable for MN	-0.298***	0.060	-0.147**	0.067	0.155*	0.091
Dummy variable for MO	-0.979***	0.079	0.188**	0.079	-0.383***	0.111
Dummy variable for WI	-0.201***	0.066	-1.504***	0.091	0.460***	0.087
R-square		0.73				
Fraction of Correct Predictions		0.65				

Note: One, two, and three stars indicate statistical significance at the 10%, 5% and 1% levels respectively.

Table 2.5 translates the estimated coefficients from table 2.4 into the elasticities of probabilities to choose alternative crops. In general, signs on the elasticities are as expected. Variables of particular interest to the policy analysis are the expected revenue for corn and fertilizer price. A 1 percent increase in the expected revenue for corn increases the probability of choosing corn and soybean by 0.3 percent and 1.1 percent, respectively. Soybean is more responsive to corn revenue increase than corn, because soybean is not a "program crop" and therefore is not subject to restrictions imposed by government commodity programs. A 1 percent increase in the fertilizer price reduces the choices of corn and soybean by 0.7 percent and 0.4 percent, respectively. Corn is more responsive to fertilizer price increase than soybean, because corn production uses more fertilizer, particularly nitrogen, than soybean. Most other variables also perform as expected. For example, a 1 percent increase in land slope reduces the choices of corn and soybean by 0.004 percent and 0.4 percent respectively, whereas it increases the choice of hay by 0.2 percent. This can be explained by the fact that producing soybean causes more soil erosion than production of corn. In addition, hay tends to be chosen on relatively steeper land in the basin.

Table 2.5. Estimated Elasticities for the Crop Choice Model

Variable	Corn Elasticity	Corn St. error	Soybean Elasticity	Soybean St. error	Hay Elasticity	Hay St. error
Expected corn revenue	0.268***	0.047	1.093***	0.070	-0.756***	0.123
Corn produced in previous growing season	0.399***	0.009	0.708***	0.013	-0.763***	0.024
Soybean produced in previous growing season	0.452***	0.006	0.015	0.009	-0.565***	0.024
Hay produced in previous growing season	0.119***	0.004	-0.011	0.007	0.250***	0.005
Variance of Corn Yield	-0.149***	0.025	0.359***	0.033	-0.256***	0.071
Mean of max. temperature during corn growing season	-3.312***	0.281	7.027***	0.462	-3.889***	0.633
St. deviation of max. temperature during corn growing season	-0.731***	0.115	1.210***	0.174	-0.787***	0.279
Mean of max. precipitation during corn growing season	-0.308***	0.067	0.967***	0.096	-0.017	0.188
Land slope	-0.004	0.009	-0.368***	0.016	0.179***	0.019
Fertilizer price	-0.724***	0.141	-0.372**	0.198	1.349***	0.381
Wage rate	-0.708***	0.150	3.126***	0.216	-0.567	0.394
Good quality land (NRCS land classes 1 and 2)	0.035***	0.010	0.086***	0.015	0.010	0.027
Average water capacity	0.477***	0.054	-0.798***	0.080	0.237*	0.136
% average organic matter	-0.020***	0.004	0.014**	0.006	-0.028***	0.011
Average soil pH	0.107	0.086	1.014***	0.124	-1.748***	0.233
Average soil permeability	0.050***	0.008	-0.119***	0.012	0.018	0.020

Note: One, two, and three stars indicate statistical significance at the 10%, 5% and 1% levels respectively.

THE EFFECTS OF CONSERVATION POLICIES

Using the estimated coefficients for the CRP and crop choice models, we simulate agricultural land use changes under the three commonly suggested conservation policies. Under each policy, simulation is conducted to examine farmers' crop choice, crop rotation, and participation in the CRP at 48,284 NRI sites in the Upper MRB, covering 77,665,100 acres. The three conservation policies include: (1) increase in the CRP annual rental rates; (2) fertilizer-use tax; and (3) incentive payments for corn-soybean rotation. Detailed description of each policy is presented in the prior section. The CRP and fertilizer-use tax are simulated for a single year in 1998. Incentive payments for corn-soybean rotation are simulated for the period of 1998-1999. Initial simulations are run based on the values of the models' independent variables in 1998 and 1999 to estimate the "baseline" probabilities of choosing one of alternatives. Using the baseline probabilities, we calculate the aggregate acreage of single-year alternative management (i.e. CRP participation and crop choice) by the following equation:

$$A_j = \sum_{i=1}^{I} \text{Prob}(j)_i \cdot xfactor_i \tag{7}$$

where A_j is the aggregate acreage of alternative j, $\text{Prob}(j)_i$ is the probability of choosing j at site i, and $xfactor_i$ is the acreage of site i reported from the 1997 NRI. Similarly, the aggregate acreage of 2-year crop rotations is calculated by:

$$A_{jj} = \sum_{i=1}^{I} \text{Prob}(j)_i^{1998} \cdot \text{Prob}(j)_i^{1999} \cdot xfactor_i \tag{8}$$

where A_{jj} is the aggregate acreage adopted to alternative j in the first and second year, respectively. $\text{Prob}(j)_i^{1998}$ and $\text{Prob}(j)_i^{1999}$ are j's probability in 1998 and 1999, respectively.

Once the baseline simulations are performed, then the effect of each conservation policy on the probabilities at each NRI site is evaluated. Some independent variables in the CRP and crop choice models are "policy variables" because these variables directly relate to the policies. For example, suppose that the policymaker increase the annual rental rates to induce more cropland to participate in the CRP. The effect of this policy can be simulated by increasing a variable representing the rental rates in the CRP model, holding other variables constant. With increased rental rates, we re-estimate the probability of CRP participation at each NRI site. Finally, based on re-estimated probabilities and equation (7), the aggregate CRP acreage after a policy change is calculated.

Table 2.6 presents the simulated effect of the CRP rental rates on CRP and major crop acreages in the Upper MRB. Overall, the CRP acreage is quite responsive to this policy. Although the acreage responses are inelastic under relatively low rental rates, significant acreage increase occurs when the rental rate is more than \$100 per acre. At the rental rate of \$150 per acre, the CRP participation expands to more than 15 million acres, accounting for 20 percent of total cropland. However, most of land enrolled in the CRP was used to produce hay and other crops before the retirement. For example, in response to \$150 per acre rental rate, the CRP acreage increases by 600 percent, and reduces hay and other crop acreages by 58 and 28 percent, respectively from the baseline.

Table 2.6 Estimated Impact of Increasing CRP Rental Rates on Agricultural Land Use in the Upper Mississippi River Basin (acres)

Rental rate ($/acre)	CRP	Corn	Soybean	Hay	Other crop
Baseline	2,211,700	27,903,865	26,004,116	7,012,697	14,532,722
10	426,700	28,082,364	26,154,352	7,330,188	15,671,495
20	525,400	28,074,749	26,149,828	7,315,804	15,599,319
30	690,500	28,060,059	26,139,278	7,281,627	15,493,636
40	933,800	28,036,168	26,125,475	7,224,544	15,345,113
50	1,305,800	27,998,806	26,092,029	7,143,124	15,125,341
60	1,776,300	27,947,220	26,052,348	7,031,424	14,857,808
70	2,250,700	27,896,031	25,999,761	6,922,749	14,595,859
80	2,831,800	27,837,635	25,943,165	6,782,169	14,270,331
90	3,534,000	27,761,372	25,864,940	6,631,131	13,873,657
100	4,332,700	27,666,261	25,755,157	6,440,821	13,470,161
110	5,214,300	27,570,522	25,648,893	6,273,016	12,958,369
120	7,018,700	27,423,160	25,402,805	6,053,982	11,766,453
130	9,239,700	27,210,531	25,168,103	5,783,823	10,262,943
140	12,273,400	26,945,314	24,817,831	5,428,405	8,200,149
150	15,551,200	26,543,826	24,434,834	5,014,700	6,120,540

Note: Total agricultural and CRP acreage = 77,665,100

In contrast to these elastic acreage responses, corn and soybean acreage decreases by only 5 and 6 percent, respectively. The U.S. average net return for corn and soybean in 1998 is estimated to be $110 per acre (Food and Agricultural Policy Research Institute 1999). At this level of CRP rental rate, both corn and soybean acreage decreases by only 1 percent. This is not surprising by taking conversion costs associated with the CRP participation into account. Although the CRP provides cost-share assistance to participating farmers who establish resource-conserving cover, this assistance covers only up to 50 percent of the participants' costs. Data from the FSA indicates that an average of cost-share assistance and other incentive payments is 145 dollars per acre. This implies that participated farmers, on average, paid at least $145 per acre when they participate in the CRP. Furthermore, once the contract expires, some landowners may wish to bring CRP acres back into production. This can also incur a substantial conversion cost to farmers. Thus, under the CRP, much high rental rates must be offered for increasing participation from "polluting" crops.

Table 2.7 illustrates the simulated effect of fertilizer-use tax on major crops in the Upper MRB. The baseline acreage of corn, soybean, hay, and other crop matches closely the values reported from the 1997 NRI. Table 2.7 shows that this policy reduces corn and soybean acreages, and increases hay and other crop acreages. This is consistent with the fact that chemical fertilizers are essential inputs for corn and soybean, whereas these are generally not for hay and other crop. As indicated by the elasticities in table 2.5, corn is much more responsive to this policy than soybean. For example, the 150 percent fertilizer-use tax reduces corn acreage by 51 percent, but reduces soybean acreage by only 17 percent. This is consistent with agronomy fact that corn requires more fertilizer for its growth. These acreage reductions are absorbed by simultaneous expansion of hay and other crop. Those crop acreages are almost doubled by the 150 percent tax. Table 2.7 also shows that, to reduce significantly corn and soybean acreages, quite high tax rate needs to be imposed on fertilizer use. For example, 150 percent tax is necessary to reduce corn acreage in half. This is consistent with previous studies suggesting high tax rates for reducing farmers' fertilizer applications (for example, Huang and Lantin 1993 and Whittaker et al 2004). Table 2.5 indicates that estimated elasticity for polluting crops is small: -0.7 for corn and -0.4 for soybean. Such small elasticities may be explained by the fact that the unit price of fertilizer is generally low. Agricultural Statistics reports that April price of anhydrous ammonia in 1998 is $0.11 per pound. Overall, however, results indicate that the fertilizer-use tax is quite effective policy for converting polluting crops to non-polluting crops, if high tax rates are imposed.

Table 2.7 Estimated Impact of Nitrogen Fertilizer Tax on Agricultural Land Use in the Upper Mississippi River Basin (acres)

Tax rate (%)	Corn	Soybean	Hay	Other crop
0	27,903,865	26,004,116	7,012,697	14,532,722
10	26,975,455	25,920,399	7,398,068	15,159,478
25	25,591,915	25,758,856	7,970,454	16,132,175
50	23,288,496	25,376,734	8,923,406	17,864,765
75	20,955,472	24,818,133	9,908,726	19,771,070
100	18,571,555	24,037,139	10,972,527	21,872,179
150	13,718,847	21,656,662	13,507,643	26,570,249
200	9,156,809	18,148,181	16,754,846	31,393,564

Note: Total agricultural acreage = 75,453,400

Table 2.8 presents the simulated effect of incentive payments for corn-soybean rotation in the Upper MRB[8]. We simulate this policy by increasing the expected revenue for the eligible crops (i.e. corn after soybean or soybean after corn) in the crop choice model. Results indicate that this incentive payments reduce effectively continuous corn production. Continuous corn reduces by 16 and 37 percent when the payment is 50 and 100 dollars per acre, respectively. Although this policy also increases corn-soybean rotation, its acreage response is quite inelastic. At the payment of 50 and 100 dollars per acre, corn-soybean rotation increases only 2 and 5 percent, respectively. These inelastic responses can be explained by two reasons. First reason is the relative scale between continuous corn and corn-soybean rotation. In the Upper MRB, corn-soybean rotation is a dominant cropping practice, accounting for 61 percent of total cropland. In contrast, continuous corn production is operated in only 6 percent of total cropland. Thus, even when all continuous corn is converted to corn-soybean rotation, its effect is limited. Second reason is the fact that only limited number of crop choices is available in the Upper MRB. The 1997 NRI reports that acreage planted to the three major crops (corn, soybean, and hay) accounts for 72 percent of total cropland in the basin. In addition, because corn is a "program crop" as well as the dominant crop, many farmers in the basin face restrictions in their crop choices imposed by government commodity program. Thus, although the incentive payments for corn-soybean rotation can decrease continuous corn, the effect is limited.

Table 2.8 The Simulated Effect of Payments for Corn-Soybean Rotation on Agricultural Land Use in the Upper Mississippi River Basin

	Continuous Corn		Corn-Soybean Rotation	
Payment ($/acre)	Acreage	Difference (%)	Acreage	Difference (%)
10	4,538,400	-2.7	46,131,900	0.4
20	4,365,000	-6.4	46,403,000	1.0
30	4,217,000	-9.6	46,600,500	1.4
40	4,051,400	-13.2	46,814,400	1.9
50	3,909,800	-16.2	47,024,600	2.3
60	3,758,100	-19.4	47,265,300	2.9
70	3,543,300	-24.0	47,535,900	3.4
80	3,306,500	-29.1	47,845,600	4.1
90	3,124,000	-33.0	48,109,700	4.7
100	2,942,800	-36.9	48,351,000	5.2
110	2,690,400	-42.3	48,673,200	5.9
120	2,407,800	-48.4	49,063,900	6.8
130	2,164,000	-53.6	49,368,100	7.4
140	1,911,800	-59.0	49,668,600	8.1
150	1,659,000	-64.4	50,021,700	8.9

CONCLUDING REMARKS

This study evaluates the effect of conservation policies on agricultural land use for adopting conservation practices in the Upper Mississippi River Basin. This objective is achieved by developing the discrete choice models to predict farmers' decisions of CRP enrollment, crop choice, and crop rotation at more than 48,000 Natural Resource Inventories sites in the basin. The estimated models are used to simulate the CRP and major crop acreage responses under the three conservation policies. Results suggest that although farmers are quite responsive to an increase in CRP annual rental rates, most of land enrolled in the CRP was used to produce "non-polluting" crops before the retirement. Thus, this policy may be effective for reducing soil erosion, but may not be effective for reducing agricultural chemical use and pollution. In contrast, the chemical fertilizer-use tax significantly reduces acreages planted to "polluting" crops (corn and soybean). Although high tax rates are required, this policy is therefore expected to be effective for reducing polluting crop acreages and pollution. Finally, results indicate that the effect of incentive payments for corn-soybean rotation is limited. Although this policy reduces significantly continuous corn production, resulting increase in corn-soybean acreage is quite small.

This study can be extended in several ways. First, this study focuses on the policy impacts at the extensive margin (changes in cropping patterns and CRP participation), but farmers may also respond to the conservation policies at the intensive margin (changes in input use). For example, when the tax is imposed on the fertilizer use, farmers may reduce their fertilizer applications as well as chemical-intensive crop acreages. Second, this study does not provide an estimate of chemical loads to surface waters. An important extension of this study is to integrate results estimated in this study with the physical model to evaluate the effect of conservation policies on fate-and-transport of agricultural chemicals in the Upper Mississippi River Basin.

ENDNOTES

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[1] These point sources were regulated by the U.S. Environmental Protection Agency (EPA) and the States through the National Pollutant Discharge Elimination System (NPDES) permit program established by the 1972 Federal Water Pollution Control Act (Clean Water Act).

[2] The 1987 amendments to the Water Quality Act (P.L. 100-4) were the first comprehensive attempt by the federal government to control and reduce nonpoint source pollution (i.e. stormwater runoff from agricultural lands, forests, construction sites, and urban areas). The amendments require the states to conduct an assessment of waters contaminated by nonpoint source pollution and to devise the best management pollution abatement plans. The amendments also provide the states with funding for implementing these plans. However, the states are not required to go beyond voluntary programs under the amendments.

[3] Hypoxic zone (or hypoxia) refers to an area in which water near the bottom containing less than 2 parts per million (ppm) of dissolved oxygen. Hypoxia can cause stress on death in bottom dwelling organisms that cannot move out of the hypoxic zone. In the northern Gulf of Mexico, hypoxia was first recorded in the early 1970s (Rabalais 2003).

[4] The type I extreme-value distribution (also called as the log Weibull distribution) is an approximation of the Normal distribution. The desirable property of the type I extreme-value distribution is that the cumulative density of the difference between any two random variables with this distribution is given by the logistic function (Kennedy 1998).

[5] Specifically, the Upper Mississippi River Basin refers to hydrologic cataloging unit code #07, defined by the U.S. Geological Survey (USGS)

[6] The first-stage sampling unit for the NRI is called primary sampling unit (PSU). PSU is an area of land, typically square to rectangular in shape, that is approximately 40, 100, 160, or 640 acres in size. The second-stage sampling units, called points, are assigned within each PSU. Certain data elements are collected for the entire PSU, while others are collected at each NRI point (NRCS 2000).

[7] The land capacity class variable consists of two characters. The first character is the soil suitability rating of agriculture, ranging from 1 to 8. Class 1 soil has a few restrictions that limit its agricultural use, class 8 soil has limitation that nearly preclude its use for commercial crop production. The second character indicates the chief limitation of the soil (NRCS 2000). This study uses only the first character of the land capacity class to construct the land quality dummy variables.

[8] Table 2.8 does not include continuous corn because it is not a common practice, accounting for less than 2 percent in the in the Upper Mississippi River Basin.

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CHAPTER 3

REDUCING NITROGEN LOADS TO CONTROL HYPOXIA IN THE GULF OF MEXICO: EASEMENTS OR TAXES?

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Submitted to *American Journal of Agricultural Economics*.

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 nitrate-N concentrations in the Mississippi River and for addressing hypoxia problems 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 Inventories 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 practices are most cost-effective among the three conservation easement policies, but can only reduce nitrate-N concentrations to a limited levels. The potential of incentive payments for corn-soybean rotations for reducing nitrate-N concentrations is even more limited. They also impose a higher cost to society than payments for conservation tillage. Payments for cropland retirement can be used to achieve the highest level of nitrate-N reduction, but impose the highest cost to society among the four policies considered in this paper.

INTRODUCTION

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 (U.S. Department of Agriculture 2003). As a consequence, agricultural runoff has been identified as a primary source of water quality problems in the surveyed rivers and streams, and agricultural nutrients are the third largest pollutants in the surveyed waters (Office of Water 2002). Modern U.S. agriculture uses a substantial amount of commercial fertilizer (nitrogen, phosphorous, and potassium). A fraction of the fertilizers applied is not taken up by crops and is transported to surface water and groundwater. In particular, dissolved nitrate-N (NO_3-N) in excessive amounts can cause eutrophication in salty waters, depleting the level of dissolved oxygen in aquatic ecosystems. For example, the Upper Mississippi River Basin (MRB) is under increasing scrutiny as a significant source of NO_3-N loadings to the Mississippi River, causing hypoxia in the Gulf of Mexico. The Upper MRB comprises only 15 percent of the drainage area of the entire MRB, but contributes more than half of NO_3-N discharged to the Northern Gulf of Mexico (Goolsby and Battaglin 1997).

The level of agricultural water pollution depends on many factors, including crop choices, crop rotations, and tillage operations. Thus, conservation programs that promote better agricultural management practices are often suggested for controlling hypoxia problems in the Gulf of Mexico. The 2002 Farm Bill represents a significant commitment of resources to conservation. It reauthorizes or establishes a number of conservation programs. Some of them provide incentive payments to farmers who adopt conservation practices (e.g. Environmental Quality Incentive Program and Conservation Security Program). However, there is little empirical evidence that these programs are cost effective compared with other commonly suggested policy instruments for controlling nonpoint source pollution such as chemical-use taxes.

The primary objective of this paper is to develop an empirical framework to estimate the social costs of alternative conservation programs (Conservation Reserve Program[1], payments for conservation tillage and corn-soybean rotation) and input-use taxes for reducing NO_3-N loads to surface waters within the Upper Mississippi River Basin and Gulf of Mexico. This objective is achieved by integrating economic and physical models. The economic models are estimated to predict crop choice, crop rotations, tillage practices, and participation in the Conservation Reserve Program (CRP) at more than 44,000 Natural Resource Inventories sites in the Upper Mississippi River Basin. Based on the predicted land use changes from the economic models, a physical model 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.

Much research has analyzed the effect of agricultural land use on water quality (e.g. Johnson et al 1991; Taylor et al 1992; Yiridoe et al 1998; Chung et al 2001; Kellie 2002). However, most of these studies focus on land use and water quality at the farm or small watershed levels. In addition, some of these studies employ unrealistic land use scenarios (e.g. all continuous corn is converted to corn-soybean rotations). A few studies has examined the issue at the region-level (Wu 1996, 1999; Wu et al 2004; Whittaker, 2003), but they only estimate the amount of runoffs beyond the edge of fields rather than the impact on stream water quality (e.g. NO_3-N concentrations). For example, in a recent paper, Wu et al. (2004) estimates the effect of incentive payments for conservation tillage and crop rotations on NO_3-N runoff in the Upper Mississippi Basin (rather than NO_3-N concentrations in the Mississippi River) and found that because the acreage responses are inelastic, these payment programs are not likely to be cost effective on their own for addressing hypoxia problem in the Gulf of Mexico. However, they did not propose any other policy alternatives. In this study, we compare the efficiency of three types of conservation payments with a fertilizer-use tax. We find that the fertilizer-use tax is much more cost effective than the three commonly suggested payment programs for conservation easements, and that the potential of these payment programs is limited for reducing NO_3-N water pollution in the Mississippi River.

This paper is organized as follows. The next section describes the study region. The third section describes the integrated modeling framework. The fourth section reports the estimated agricultural land use and the resulting water quality under different policy scenarios. The last section summarizes and concludes this study.

THE STUDY REGION

The Upper Mississippi River Basin (MRB) encompasses approximately 480,000 square kilometers in six states: Illinois, Indiana, Iowa, Minnesota, Missouri, and Wisconsin[2]. The three major rivers in the Upper MRB 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 (figure 3.1). Thus, the Upper MRB is referred to as this area hereafter.

The climate of the Upper MRB is subhumid continental. The average monthly maximum temperature ranges from -9.8 degrees C° in January in the Central Minnesota, to 31.7 degrees C° in July in the Central Missouri. The average annual precipitation increases from 575 millimeters in the Western part of Minnesota, to 981 millimeters in the Central part of Illinois. About 75 percent of the annual precipitation falls during corn growing season from April to October. Soil type in the basin ranges from heavy, poorly drained clay soil to light, well-drained sands.

In the most parts of the Upper MRB, agriculture is the dominant land use. Table 3.1 indicates 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 total land planted to row crops but has gained increasing attention due mainly to its environmental benefits and reduced operation costs[3]. In this basin, 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.

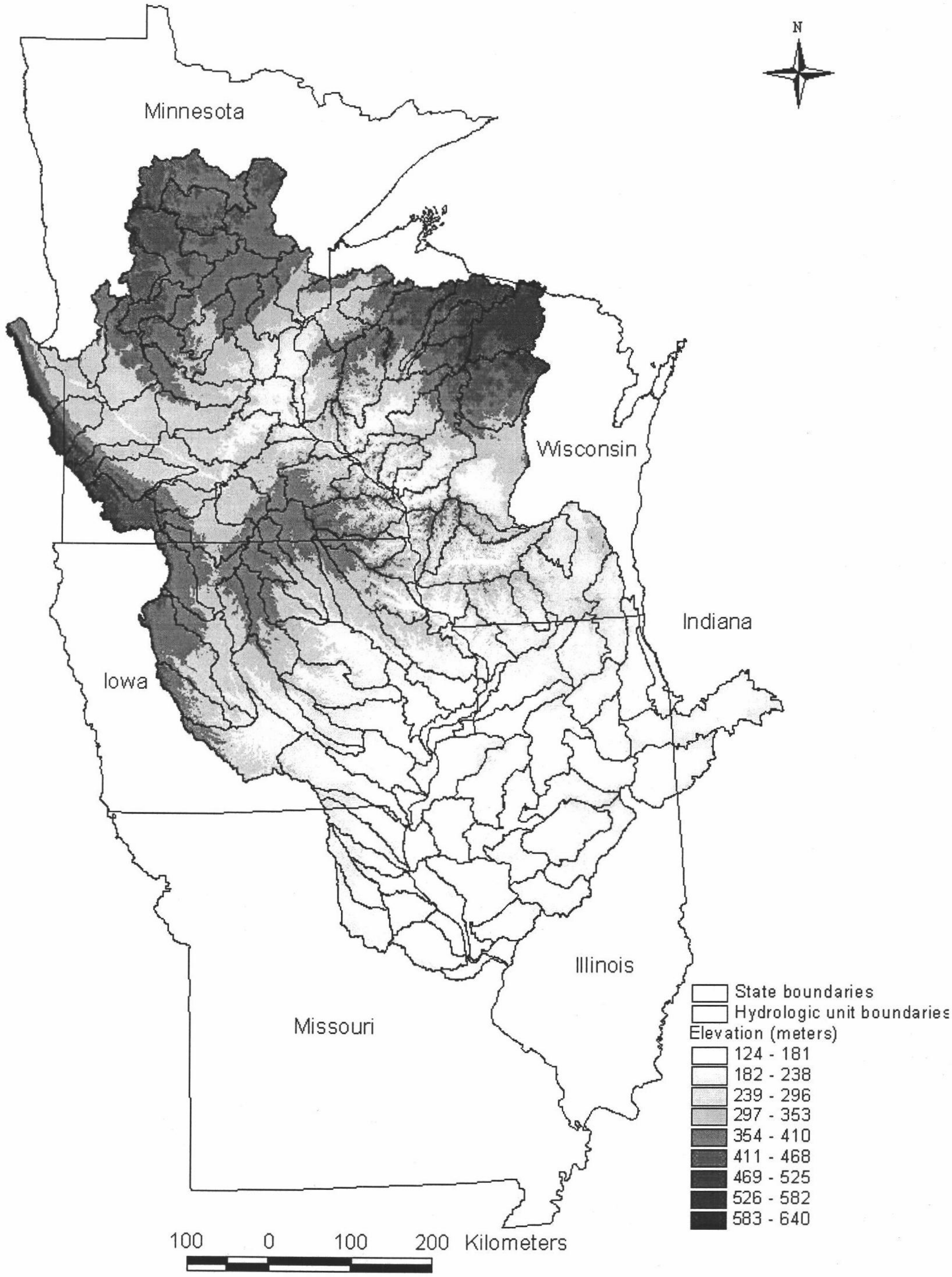

Figure 3.1 The Upper Mississippi River Basin

Table 3.1 Major Land Uses in the Upper Mississippi River Basin Above Missouri River[a]

Land use	Area (acres)	Share (%)
Agriculture / Pasture	73,122,400	69.1
Corn-soybean rotation - conventional tillage[b]	25,637,055	24.2
Corn-soybean rotation - conservation tillage[c]	19,574,345	18.5
Continuous corn - conventional tillage	3,992,416	3.8
Continuous corn - conservation tillage	674,584	0.6
Hay	6,486,400	6.1
Other crop / Pasture	14,152,200	13.4
CRP	2,605,400	2.5
Forest (mixed, deciduous)	24,537,479	23.2
Urban (residential, quarries, commercial, barren rock)	5,611,474	5.3
Water	2,599,727	2.5
Total	105,871,081	100.0

[a] Double ruled rows indicate a breakdown of agriculture / pasture.
[b] Including soybean-corn rotation under conventional tillage.
[c] Including soybean-corn rotation under conservation tillage.

THE INTEGRATED MODELING FRAMEWORK

This section presents the integrated modeling framework that we use to estimate the social costs of alternative policies for reducing NO_3-N loads to surface water within the Upper Mississippi River Basin and Gulf of Mexico. The structure of the framework is shown in figure 3.2.

The framework is based upon the Natural Resource Inventories (NRI), conducted by the Natural Resource Conservation Services (NRCS). The NRI is a scientifically based, longitudinal panel survey of the Nation's soil, water, and related resources, designed to assess conditions and trends every five years (NRCS 2000). The NRI 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 NRIs also contain an expansion factor, which indicates 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 Upper MRB, there are a total of 101,893 sites and, among these sites, 44,221 sites are used for agriculture and CRP in 1997. Using the 1982, 1987, 1992, and 1997 NRIs and other site-specific information about production practices and physical characteristics, the economic models are estimated to predict agricultural land use before and after a policy change in the Upper MRB.

Changes in land use predicted by the economic models are then used as inputs for the physical model, the Soil and Water Assessment Tool (SWAT), to predict NO_3-N concentrations in the Mississippi River before and after a policy is implemented. 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 detail both the economic and physical components of the framework.

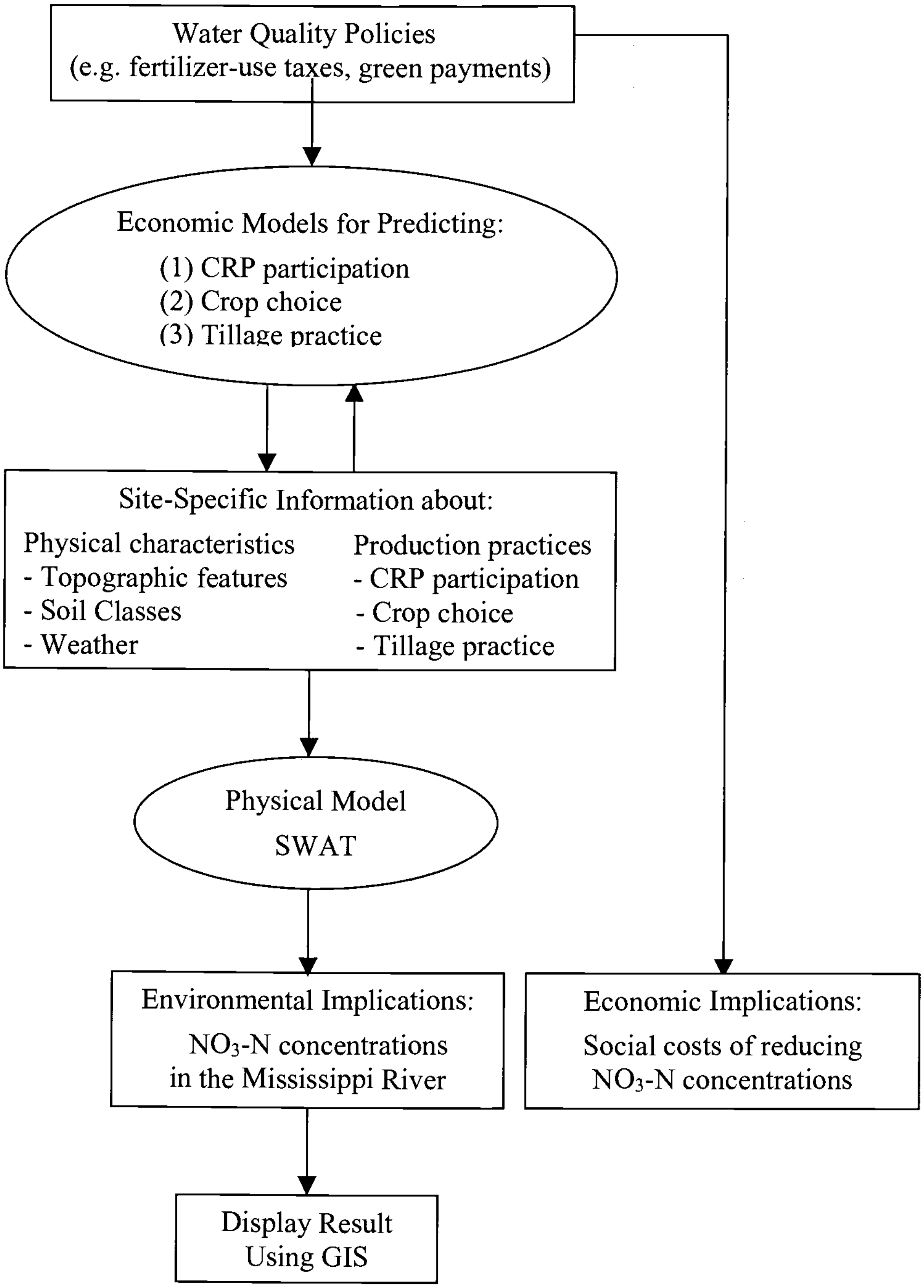

Figure 3.2 The Analytical Framework

The Economic models

Three econometric models are developed in this study to predict farmers' decisions regarding: (1) 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 Upper MRB. 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. These econometric models are specified as logistic functional forms to predict the probability of choosing each of the land use options at each NRI site. The option with the highest probability is assumed to be the choice at the site. For example, a site is assumed to enroll in CRP if the predicted probability of participating the program is greater than or equal to the probability of not participating the program. These econometric models have been documented and published in Wu et al. (2004) and are available upon request.

The three logistic models are used in the following order. First, the CRP model is used to predict which site is enrolled in the CRP. Second, the crop choice model is applied to the sites not participating in the CRP. The crop choice model assigns one of the crops (corn, soybean, hay, and other crop) to each of the NRI sites for the period of 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).

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. 2002a). 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, watersheds 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. 2002b). This study, in particular, 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 an 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. The use of multiple subbasins has an advantage when major land uses and soil properties are different across subbasins (i.e. spatial heterogeneity exists). By partitioning the watershed into subbasins, spatial heterogeneity can be taken into account to improve simulation accuracy.

Each subbasin can be further divided into hydrologic response units (HRUs), which are virtual units of SWAT simulations. HRUs do not provide spatial information (i.e. geographic location of each HRU within the subbasin is not known) but do represent unique combinations of land use and soil type. For example, if a subbasin includes two land uses and two soils, 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.

Data and Model Development

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.

The watershed delineation carries out advanced GIS functions to aid the user in segmenting watersheds into hydrologically connected subbasins for use in watershed modeling with SWAT. The primary information required for this process is topography in the watershed, which is used to calculate slope and slope length in each cell, to determine hydrologic channel, and to delineate subbasins. We use the 1-degree Digital Elevation Model (DEM) data obtained from Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) version 3 CD developed by the Environmental Protection Agency. Figure 3.1 illustrates topographic features in the Upper MRB. Because the results from the economic model is geographically partitioned by the USGS's 8-digit hydrologic HUC boundaries (figure 3.3), the watershed delineation must follow the same boundaries for the integration of the economic and physical models. Because AVSWAT delineates the watershed only automatically based on the DEM grid, we carefully defined the locations of stream outlets to bring subbasins close to 8-digit HUC boundaries. Reach File Version 1, digitized stream network developed by the

USGS, was used to increase the accuracy of the process. This gives us a total of 118 subbasins, following the 8-digit HUC boundaries (figure 3.3).

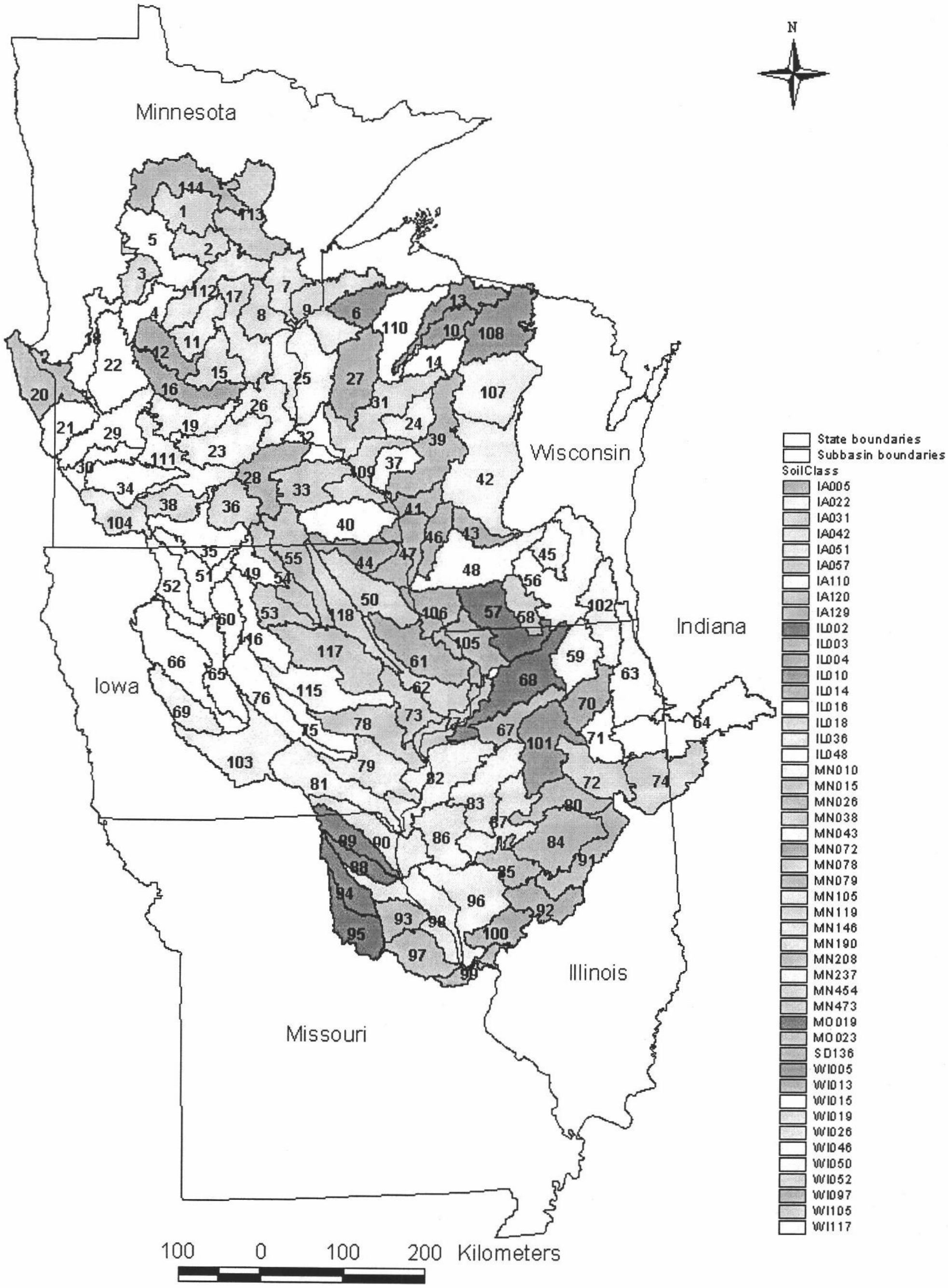

Figure 3.3 Subbasin Boundaries and Dominant Soil Types
in the Upper Mississippi River Basin

The land use and soil classification identifies unique combinations of land use and soil type for each subbasin, based on spatial information on land use and soil classes. Land use and soil types are used to construct HRUs. Soil classification is performed using State Soil Geographic (STATSGO) digital soil association map developed by the NRCS. STATSGO consists of a broad based inventory of soil and nonsoil areas that occur in a repeatable pattern on the landscape. Each STATSGO polygon contains multiple soil series and the aerial percentage of each series is provided (NRCS 1994). Once the soil series are selected, AVSWAT extracted required information from an associated database. Extracted information includes texture, bulk density, saturated conductivity, available water capacity, and organic carbon. To facilitate the analysis, this study used only the dominant soil type for each subbasin. The resulting soil map is presented in figure 3.3. Land classification is performed based on the Land Use and Land Cover (LULC) spatial map developed by the USGS. The LULC data provides spatial information on broad land use classes, such as urban, agriculture, forest, and water. Detailed agricultural land use from the economic models is integrated into the LULC data by the following steps. First, AVSWAT calculates areal percentages of broad land uses (agriculture, forest, urban, and water) for each subbasin based on the LULC map. Agricultural land use is then further divided into 9 land use classes based on the economic models (7 land use classes listed in table 3.1 plus soybean-corn rotation under conventional and conservation tillage). For example, suppose that 45 percent of one subbasin is identified as agricultural land, and the economic models predict that 10 percent of agricultural land is allocated to corn-soybean rotation with conservation tillage. Then, by integrating these estimates, AVSWAT determines that corn-soybean rotation with conservation tillage accounts for 4.5 percent (45*0.1) of total land area in the subbasin. This procedure is applied to each of 118 subbasins in the Upper MRB. As a result, we obtained a total of 12 land use classes (9 agricultural land use classes and 3 non-agricultural land uses[4]), and a total of 1,410 HRUs in the Upper MRB. The percentage of each land use class in the basin is presented in table 3.1.

The land management schedules describe management practices for each land use in the subbasins (e.g. timing and amount of fertilizer applications). The schedule can be different among subbasins or identical in the watershed. This study applied the same management schedule for a given type of land use in the Upper MRB to facilitate the simulations (table 3.2). The schedule for each of the agricultural land uses basically follows the studies by Neppel (2001), McIsaac et al. (1995), and Kellie (2002), and suggestions from local agricultural experiment stations. Although many types of tillage practices are referred to as conservation tillage, we use no-till[5] as a representative of conservation tillage practice in the basin. For land used for producing "other crops" and non-agriculture (i.e. forest and urban), specific land management schedules are not created and we followed the default schedules generated by SWAT.

Finally, SWAT requires several weather variables for the hydrologic balance in the simulation. These variables include precipitation, maximum and minimum air temperature, solar radiation, wind speed, and relative humidity. If daily precipitation and air temperatures are available, they can be input directly into the model. If not, daily values for these variables are generated by SWAT built-in weather generator. Solar radiation, wind speed, and relative humidity are always generated. In this study, all weather information required for SWAT simulations are generated using monthly weather statistics reported from about 60 weather station in the Upper MRB. The ArcView interface selected automatically the nearest weather station for each subbasin and generated climatic variables based on historical statistics.

Table 3.2 Management Scenarios for Agricultural Land Use[a]

Agricultural practice	Management Scenario
Corn-Soybean / Conventional Tillage[b]	Two-year rotation of corn/soybean. In spring, the land is tandem disk plowed. Before planting corn in late April, 168 Kg/ha anhydrous ammonia is applied. After corn harvest in mid October, the soil is chisel plowed. Secondary tillage is same as tillage operation before planting corn in the first year. Soybean is planted in mid May and harvested in early October. After harvesting corn, no tillage is operated.
Corn-Soybean / No-till[b]	Basic operations are same as above except tillage operation. Under no-till scenario, corn and soybean are grown without any tillage operation. The only soil disturbance is fertilizer injection before planting corn.
Continuous corn / Conventional tillage	Single year operation. In spring, the land is tandem disk plowed. Before planting corn in late April, 168 Kg/ha anhydrous ammonia is applied. After corn harvest in mid October, the soil is chisel plowed.
Continuous corn / No-till	Same as the C-C-NT, but no tillage are operated to minimize the soil disturbance
Hay	5-year operation. In the first year, bermudagrass is planted in mid-May. Grazing are operated three times in each year. No fertilizer N is applied.
CRP	3-year operation. Meadow bromegrass is planted in mid-may of the first year. Grazing are operated twice in each year. No fertilizer N is applied.

[a] Other crop follows SWAT's default management schedule.

[b] Soybean-corn rotations basically follow corn-soybean rotation scenarios. The only difference is that soybean is planted in the first year and corn is planted in the following year.

RESULTS

Agricultural Land Use Changes Under Conservation Policies

Using the economic models, we evaluate the effect of the four conservation policies on agricultural land use in the Upper MRB. The four policies are: (1) taxes on chemical fertilizer use; (2) increases in CRP rental rates; (3) incentive payments for conservation tillage; and (4) incentive payments for corn-soybean rotations. Initial simulations are run based on values of the models' independent variables in 1988 and 1999. The estimated land use serves as a baseline. We then evaluate land use changes under different policies. Some variables used in the economic models are "policy variables" because these variables are directly related to the policies. For example, suppose a tax is imposed on chemical fertilizer use. The effect of this policy is simulated by increasing the price of chemical fertilizer in the crop choice model, holding other variables constant. With increased fertilizer prices, we re-calculate the probability of choosing alternative crops at each NRI site in the Upper MRB.

Figure 3.4 presents the simulated effects of the chemical fertilizer-use tax on major crop acreages in the Upper MRB. The predicted acreages of corn, soybean, and hay at the baseline closely match the acreages reported by the 1997 NRI. Under this policy, the corn and soybean acreages decline, while hay and other crop acreages increase simultaneously as the tax rate increases. This is consistent with the fact that chemical fertilizer is an essential input for corn and soybean, whereas it is not for hay and other crop. Corn acreage is more responsive to the tax than soybean acreage, because corn requires more chemical fertilizer for its growth. Figure 3.4 implies that, to reduce significantly corn and soybean acreage, quite high tax rate needs to be imposed on fertilizer use. For example, about 150 percent tax is required to reduce corn acreage in half. This is consistent with previous studies suggesting high tax rates to reduce farmers' fertilizer use significantly (for example, Huang and Lantin 1993 and Whittaker et al 2003). Overall, the acreage of "polluting" crops (i.e. corn and soybean) under the fertilizer-use tax is quite responsive. Thus, this policy is quite effective in converting polluting cropland to "non-polluting" cropland.

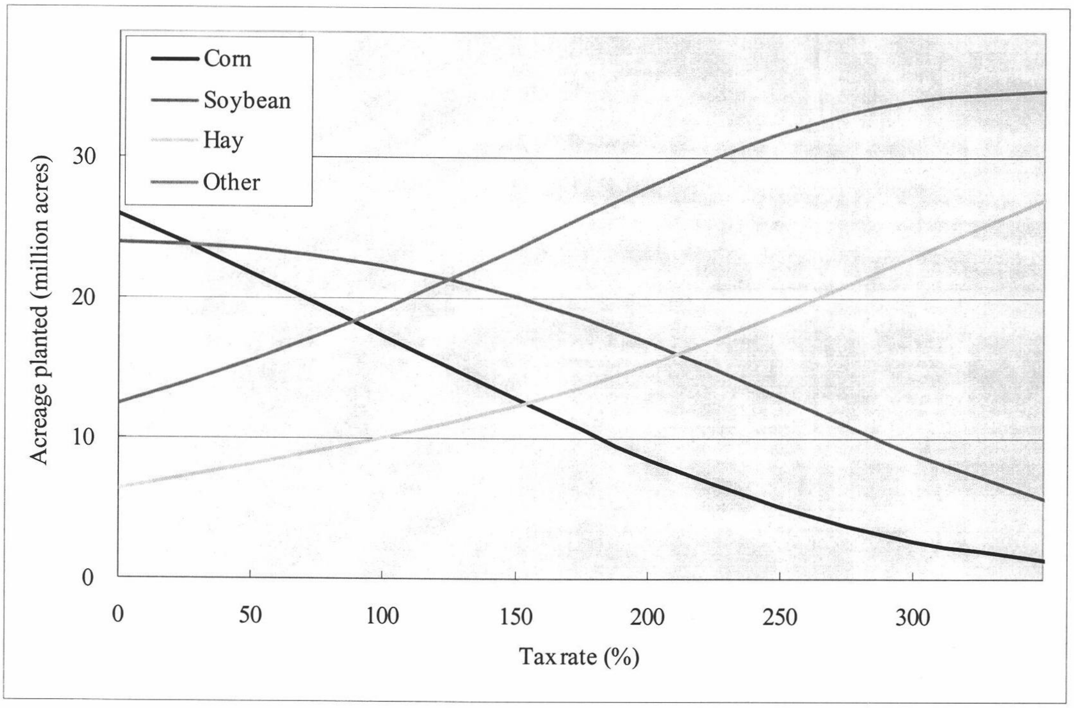

Figure 3.4 The Estimated Crop Acreage Responses to the Fertilizer-Use Tax in the Upper Mississippi River Basin

Figure 3.5 shows the simulated effects of CRP rental rates on CRP acreage in the Upper MRB. This policy is simulated by increasing a variable representing the CRP annual payment level in the CRP participation model. As the rental rates increase, the CRP acreage increases continuously. Although the CRP acreage responses are inelastic under relatively low rental rates, significant acreage increase occurs at the rental rate from $100 to $200 and above $250 per acre. However, most of land enrolled in the CRP from $100-$200 is used to produce hay and other crop before the retirement. Corn and soybean acreages are not responsive when the payment level is below $250 per acre.

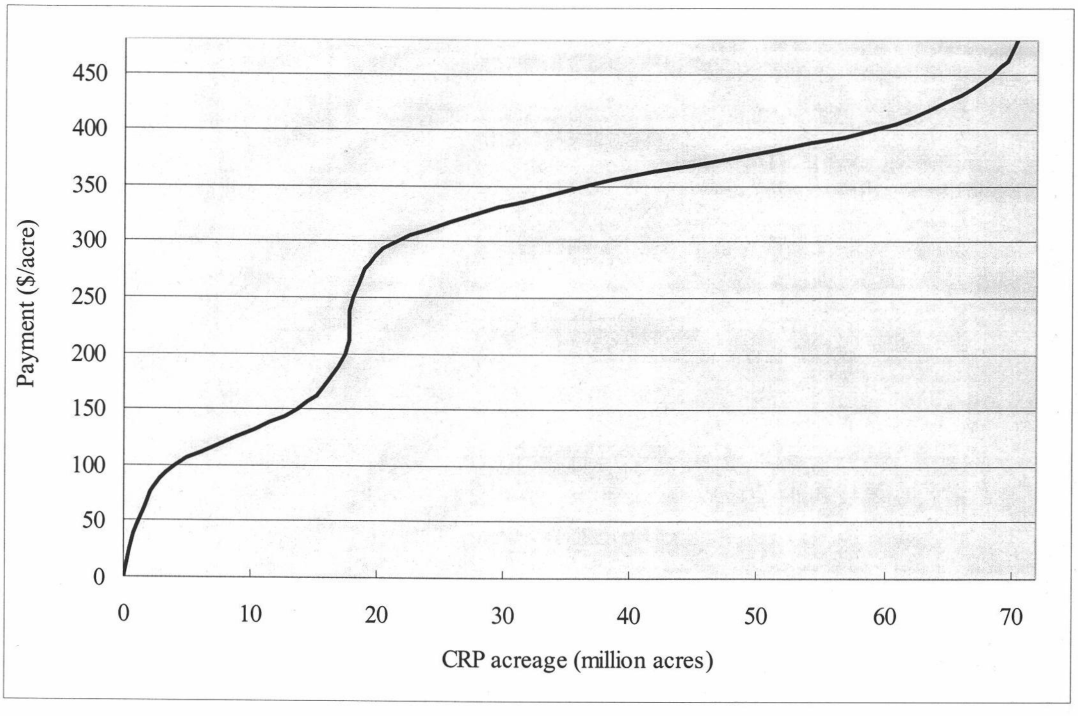

Figure 3.5 The Estimated CRP Acreage Responses in the Upper Mississippi River Basin

At the rental rate of $250, nearly 18 million acres (25 percent of cropland) is enrolled in CRP. However, as will be seen later in this paper, because most of the land was planted to "non-polluting crops" (i.e. hay and other crops), it does not significantly reduce NO_3-N concentrations when CRP rental rate is below $250 per acre. Results imply that to promote polluting crops to participate in the CRP, necessary payment levels are much higher than per acre profits for producing polluting crops. For example, the U.S. average net return for corn and soybean in 1998 is estimated to be $110 per acre (Food and Agricultural Policy Research Institute 1999). This disparity can be explained by conversion costs in the CRP. Although the CRP provides cost-share assistance to participated farmers who establish resource-conserving cover on eligible cropland, this assistance covers only up to 50 percent of the participants' costs. Data obtained from the Farm Service Agency indicates that an average of cost-share assistance and other incentive payments is 145 dollars per acre. This implies that participated farmers, on average, paid at least $145 per acre when they participate in the CRP. Furthermore, once the contract expires, some landowners may wish to bring CRP acres back into production. This can also incur a substantial conversion cost to farmers. Thus, annual rental rates need to be higher than net return for inducing polluting crops to enroll in the CRP.

Figure 3.6 depicts the simulated effects of incentive payments for conservation tillage in the Upper MRB. Under this payment policy, corn and soybean acreages under conservation tillage receive a payment. This policy is simulated by increasing a variable representing the difference between the production costs for conventional tillage and conservation tillage in the tillage model. The estimated results indicate that farmers are very responsive to this policy. At the baseline, acreage share of conservation tillage is 40 percent. A payment of $50 and $100 per acre increases its share to 61 and 78 percent respectively. A payment of $150 per acre results in 88 percent of corn and soybean acres adopting conservation tillage. The acreage response curve in figure 3.6 is nearly vertical when the payment rate is above $250 per acre, indicating that nearly all cropland is converted to conservation tillage. Our estimates of acreage adoption for conservation tillage requires much higher payments than those estimated by Kurkalova et al (2003). For example, their empirical study indicates that 30 percent increase in conservation tillage acreage requires a payment of about $11 dollar per acre, whereas $33 per acre is suggested in this study. This may be due to differences in policy design and study region. Their study assumes that payments are offered for all crops (corn, soybean, and other crops), while payments in this study are offered only for corn and soybean. In addition, their study focuses on Iowa, where conservation tillage has historically been common practice. The NRI 1992 indicates that conservation tillage acreage accounts for 61 percent of total cropland, whereas it accounts for 21 percent in other five states (Illinois, Indiana, Minnesota, Missouri, and Wisconsin) in the Upper MRB. Besides those differences, high conservation payments estimated in this study may be reasonable due to two reasons. First, crop yields under conservation tillage are highly affected by various physical conditions. 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. Second, conservation tillage requires special equipment such as a no-till planter and shielded sprayer. It also requires timely chemical weed control, which many past-time farmers may not be able to do.

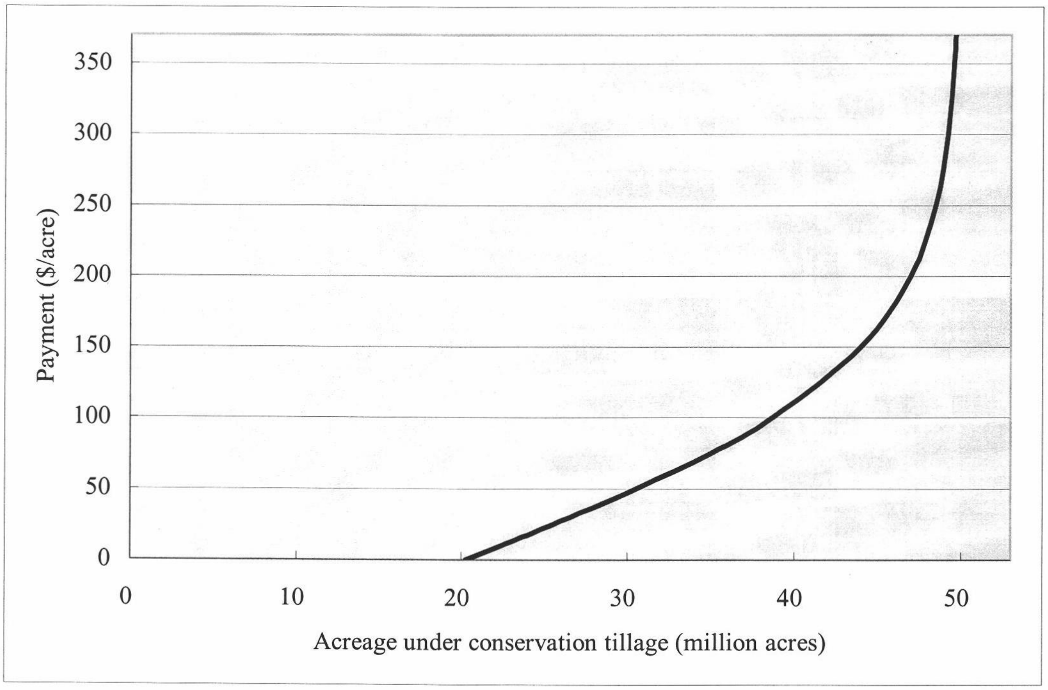

Figure 3.6 The Estimated Acreage Responses to the Incentive Payments for Conservation Tillage in the Upper Mississippi River Basin

Finally, figure 3.7 illustrates the simulated effects of the incentive payments for corn-soybean rotations. This conservation policy rewards farmers who plant corn after soybean, or soybean 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. Results indicate that a payment of $50, $100, and $150 per acre increases share of corn-soybean rotation acreage to 88, 90, and 94 percent, respectively, from a baseline share of 86 percent. This indicates that although this conservation payment increases corn-soybean rotation, it is not likely that this payment will have a large impact on crop choices and NO_3-N water pollution, a topic which we focus on next.

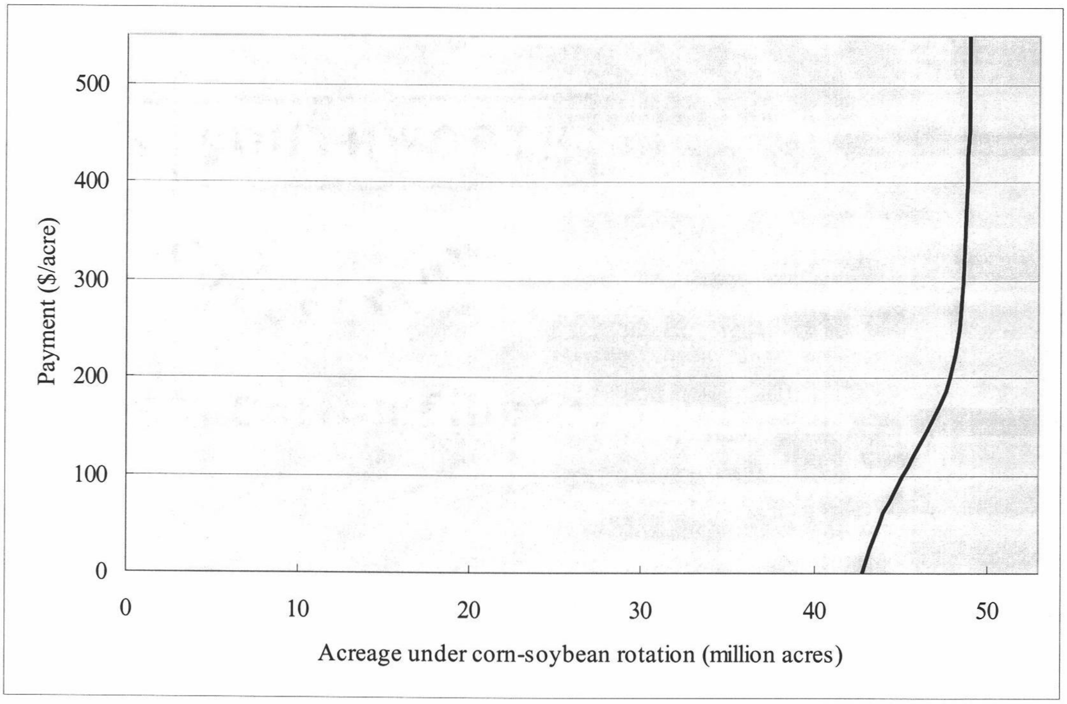

Figure 3.7 The Estimated Acreage Responses to the Incentive Payments for Corn-Soybean Rotation in the Upper Mississippi River Basin

SWAT Model Validation Results

Using the land use information under the baseline scenario, the SWAT model is run for 20 years. Simulated monthly average of streamflow is compared to 20-year average of measured stream flow from the USGS stream gage station on the Mississippi River in the town of Grafton, Illinois (figure 3.8). Overall, SWAT predicts the streamflow reasonably well. The difference between the measured and simulated annual average streamflow is less than 5 percent. However, the model tends to underpredict in late winter and early spring, and overpredict in early winter. This divergence can be mostly explained by the difference in the measured and simulated levels of precipitation.

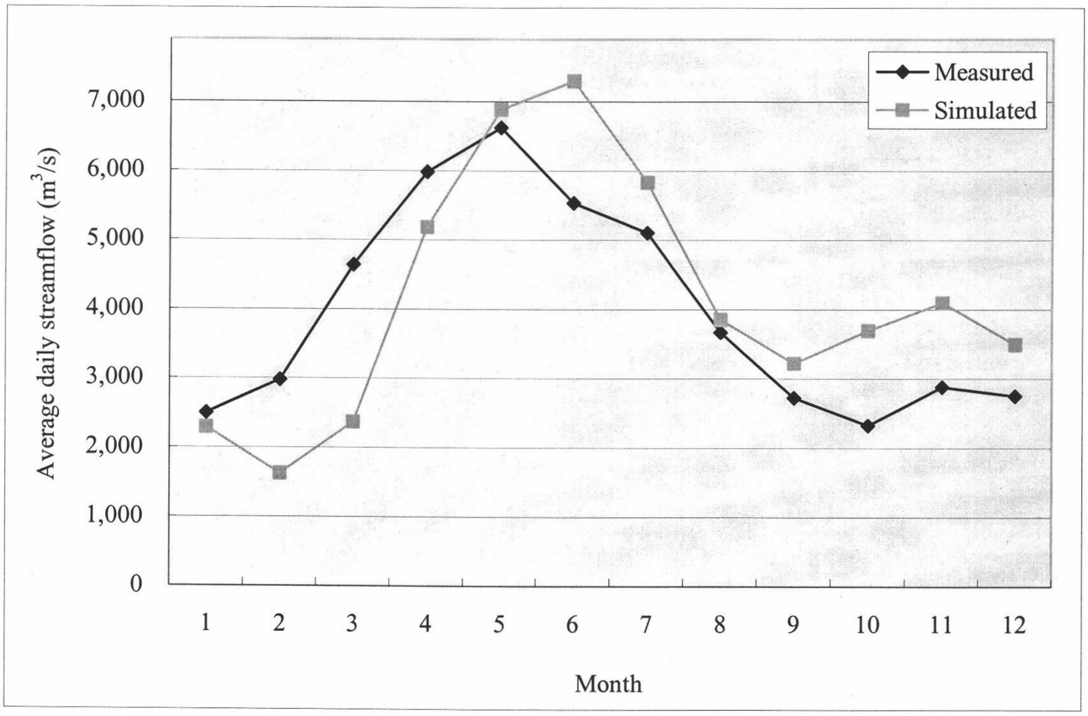

Figure 3.8 Measured and Simulated Monthly Average Streamflow at Grafton, Illinois

Next, the annual average of estimated NO_3-N concentrations is compared to the annual average of 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 (table 3.3). Goolsby and Battaglin (1997) reports that commercial nitrogen fertilizer and legume nitrogen fixing contribute 65 percent of total nitrogen inputs in Mississippi River Basin above Missouri River (table 3.4). 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 Goolsby and Battaglin study.

Table 3.3 Measured NO_3-N concentrations Near Grafton, Illinois during 1998-2000[a]

	Month												
Year	1	2	3	4	5	6	7	8	9	10	11	12	Average
1998	4.88	4.22	4.09	4.71	5.15	5.02	4.55	2.35	1.50	1.58	3.78	3.51	3.78
1999	N/A	4.26	3.66	3.72	5.47	5.62	3.93	3.17	1.59	1.52	1.21	1.37	3.23
2000	1.78	2.23	2.71	1.61	4.02	4.59	4.08	1.91	0.64	1.38	1.54	N/A	2.41
Average	3.33	3.57	3.49	3.35	4.88	5.07	4.19	2.48	1.24	1.49	2.18	2.44	3.14

[a] Values reported at USGS stream gage station #05587455.

Table 3.4 Estimates of Annual Nitrogen Inputs in the Mississippi River Basin

Source of nitrogen	Input (metric tons)	Share (%)
Commercial nitrogen fertilizer	1,898,800	54.3
Legume (soybean and alfalfa)	375,500	10.7
Livestock manure	914,100	26.1
Atmospheric wet deposition of nitrate as N	107,700	3.1
Human domestic waste	188,600	5.4
Industrial point sources	12,600	0.4
Total	3,497,300	100.0

Adapted from Goolsby and Battaglin (1997)

Figure 3.9 illustrates the estimated NO_3-N concentrations at the end of the reach in each subbasin in the Upper MRB. 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 tends 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 the subbasins 111 and 23. These subbasins have intensive row crop production and higher precipitations than the basin average. Lower concentrations occur at many subbasins below these subbasins due mainly to less intensive row crop production. In the Upper MRB, 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 pollution in the Upper MRB. Previous state water quality surveys show that the level of NO_3-N concentrations in the public water supply in Des Moines, Iowa, often exceeds the nitrate maximum contaminant level (MCL) of 10 mg/L set by the EPA (USGS 2003).

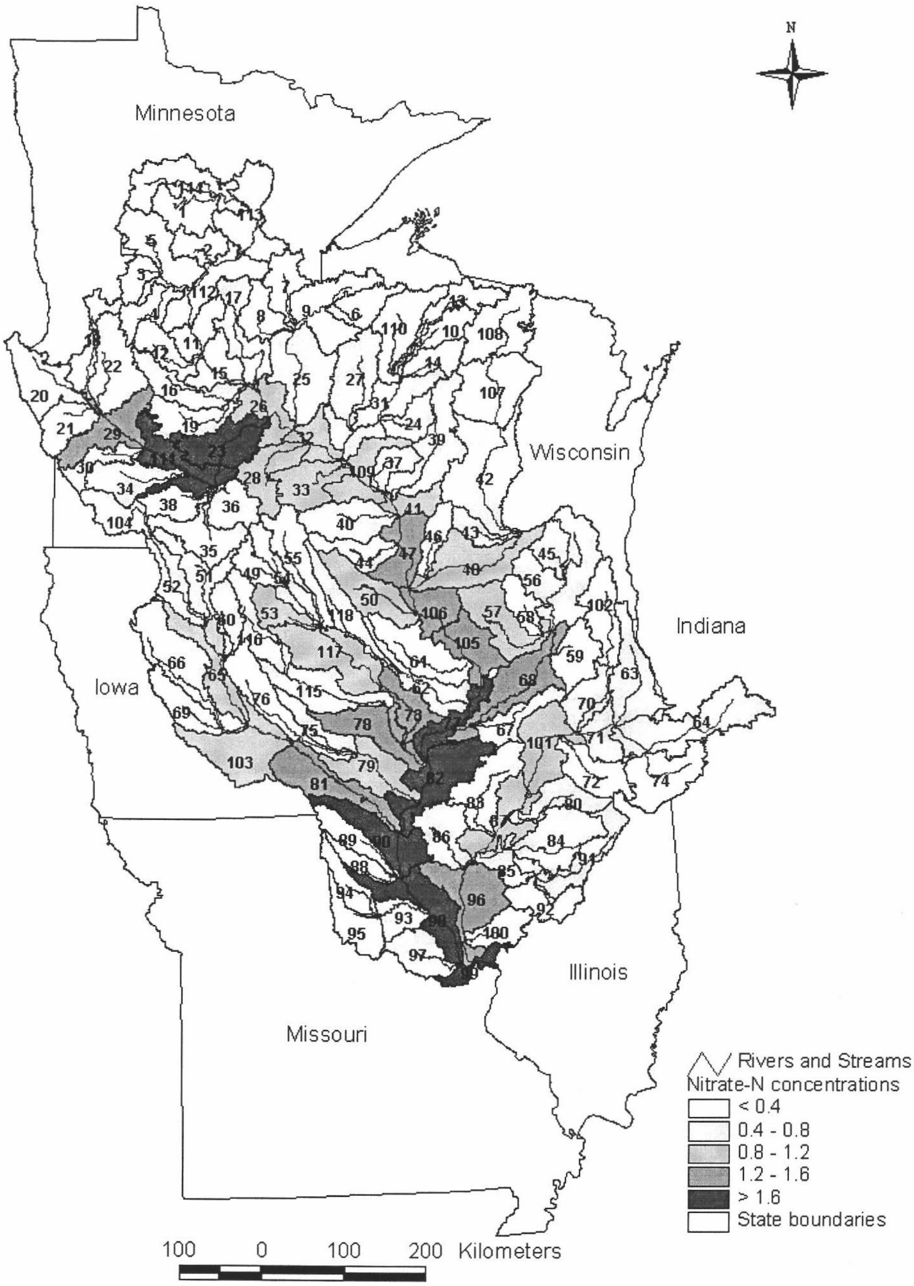

Figure 3.9 The Estimated NO_3-N Concentrations at the Reach of Subbasins in the Upper Mississippi River Basin

Estimating the Social Costs

This section evaluates the cost effectiveness of four conservation policies to reduce NO_3-N concentrations in the Mississippi River. The social costs to achieve different levels of reduction in NO_3-N concentrations under each of the four policies are shown in figure 3.10. These costs are estimated by combining simulation results from the economic and physical models. Specifically, for each targeted level of NO_3-N reduction, the required payment level is determined through simulations for each policy. The area under the acreage response curves (figure 3.5, 3.6, and 3.7) between the vertical axis and the acreage corresponding to the required payment level is then estimated as the social cost to achieve the targeted level of NO_3-N reduction. Figure 3.10 shows the level of conservation payment and corresponding social cost. In the figure, it is assumed that the policymaker offers a payment of A dollars per acre and C acres adopt the program. Then, social cost is estimated by the difference between the program's expenditure (OABC) and farmers' surplus (OAB), resulting in an area OBC.

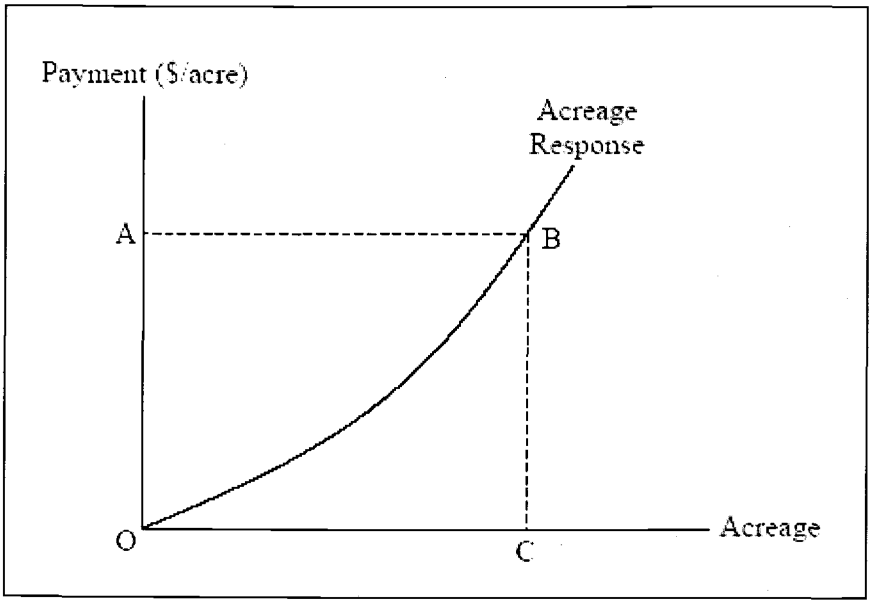

Figure 3.10 Social Cost Under the Conservation Payment Program

The social cost under the chemical fertilizer-use tax equals the loss in aggregated farm profit under the tax minus the government tax revenue. The aggregate farm profit is calculated by $\sum_{i=1}^{I} A_i(p_i y_i - c_i)$, where A_i is the total acreage planted to crop *i*, p_i is the *i*'s crop price, y_i is the yield per acre of crop *i*, and c_i is the per acre production cost of producing crop *i*. A_i is estimated from the economics model with the different levels of tax. All crop prices and per acre yields for soybean and hay are obtained from *Agricultural Statistics 2000*. Per acre production costs are adapted from the estimates by Duffy (2000). Because corn yields are influenced by the fertilizer application rate, corn yields are calculated using the yield response functions developed by Stecker et al. (1995). These quadratic functions estimate yield responses of corn to fertilizer nitrogen under continuous corn and corn-soybean rotation. The yields of soybean and hay are assumed not to be affected by the fertilizer-use tax.

Figure 3.11 shows that the fertilizer-use tax is most cost-effective for reducing NO_3-N concentrations in the Mississippi River. 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.

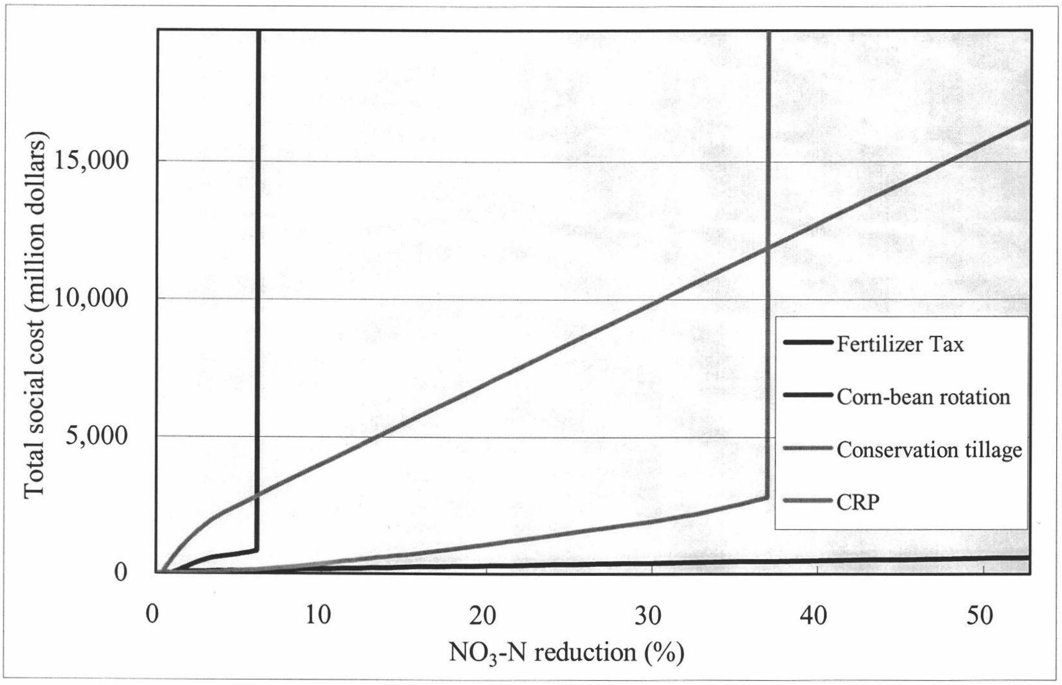

Figure 3.11 Simulated Levels of NO_3-N Reductions and Required Social Costs Under Alternative Conservation Policies in the Upper Mississippi River Basin

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 because 86 percent of corn and soybean acreages are already under corn-soybean rotations even without any government subsidy.

CONCLUSIONS

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

Results 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 of incentive payments for corn-soybean rotations are even more limited. Furthermore, the payments impose a higher cost to society than payments for conservation tillage. The Conservation Reserve Program can be used to achieve the highest NO_3-N reduction but it imposes the highest cost to the society among the four policies considered in this study.

The 2002 Farm Bill represents a significant commitment to conservation by establishing and reauthorizing several payment programs to reduce agricultural water pollution. Although some of these programs have been criticized as political payments and their cost effectiveness are in question, there is 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 the conservation payments when the objective is to reduce NO_3-N concentrations in surface waters within the Upper Mississippi River Basin and Gulf of Mexico.

ENDNOTES

[1] The Conservation Reserve Program (CRP), administrated by the Farm Service Agency (FSA), is a voluntary land retirement program for agricultural landowners. The CRP was originally enacted in 1985, and remains the largest agricultural land retirement program in the U.S. Through the CRP, agricultural landowners receive annual rental payments and cost-share assistance to establish resource-conserving cover crops on eligible cropland (FSA 2003a). The primary objectives of the CRP are: (1) reducing soil erosion and sedimentation in streams and lakes; (2) establishing wildlife habitat and enhance forest and wetland resources; and (3) protecting the Nation's ability to produce food and fiber.

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

[3] 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.

[4] Some subbasins do not contain the hydrologic response unit for water because, in these subbasins, water's areal shares are too small to be modeled.

[5] No-till is a method of farming where the soil is left undisturbed from the harvest of one crop to the beginning of next growing season. Soil disturbance occurs only when fertilizer is applied before growing season, and when crop is harvested.

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CHAPTER 4

TARGETED VS. UNIFORM INPUT-USE TAXES FOR REDUCING NITRATE WATER POLLUTION

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To be submitted to *Ecological Economics*

ABSTRACT

Previous studies disagree about the extent to which a targeted chemical-use tax outperforms an uniform chemical-use tax. This study estimates the relative efficiency of targeted and uniform fertilizer-use taxes for reducing nitrate-N water pollution in the Des Moines Watershed in Iowa. This objective is achieved by integrating economic and physical models. The economic model predicts farmers' crop choices, crop rotations, and conservation tillage adoption in the watershed. Predicted changes in crop choices, crop rotations and tillage practices under the fertilizer-use taxes are then integrated into the Soil and Water Assessment Tool to assess the level of nitrate-N runoff from the 9 subbasins in the watershed. In contrast to previous studies, this study finds that the targeted fertilizer-use tax reduces the aggregate farm profit loss under the uniform fertilizer-use tax by up to 30 percent.

INTRODUCTION

Nitrate-N (NO_3-N) is one of the most commonly detected chemicals in U.S. waters. NO_3-N itself is generally not a concern for human health, but it can be converted to nitrite in the digestive tract, causing serious human health risks[1]. Although the Environmental Protection Agency (EPA) set the maximum contaminant level (MCL) of 10 milligram per liter (mg/L), NO_3-N in drinking water often exceeds the MCL in the Upper Mississippi River Basin (Center for Health Effects of Environmental Contamination 2001). This basin is also under increasing scrutiny as a significant source of NO_3-N loads to the Gulf of Mexico, causing one of the largest hypoxic (low dissolved oxygen) zone in the world[2].

Modern U.S. agriculture has been identified frequently as a major contributor of NO_3-N to surface waters. The 2000 National Water Quality Inventory reports that agriculture is the primary source of water quality problems in the surveyed rivers and streams. The inventory also reports that agricultural nutrients, including NO_3-N, are the third largest pollutants in the surveyed waters (Office of Water 2002). Because agricultural pollutants come from many diffuse sources, it is not easily monitored and controlled. Thus, reducing agricultural water pollution is one of the biggest challenges faced by the federal and state governments.

Numerous studies have evaluated empirically the effect of alternative policy instruments for reducing NO_3-N loss from agriculture (e.g. Johnson et al 1991; Taylor et al 1992; Mapp et al 1994; Wu 1995; Wu et al. 2004; and Tanaka and Wu 2003b). For example, Tanaka and Wu (2003b) evaluate the relative efficiency of a uniform fertilizer-use tax versus three conservation payments for reducing NO_3-N concentrations in the Upper Mississippi River. They find that the uniform fertilizer-use tax is much more cost-effective than any of the three conservation payments (Conservation Reserve Program, incentive payments for corn-soybean rotation, and incentive payments for conservation tillage). However, they did not consider other tax policies, such as a targeted (non-uniform or differentiated) 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. However, their estimates of per acre nutrient runoff are not physically based. Instead, they use simple regression equations to estimate nutrient runoff from agriculture. Helfand and House (1995) derive the opposite conclusion. They find that the uniform tax is almost as cost-effective as the targeted tax. However, their differentiated tax varies across only 2 soils; other sources of spatial heterogeneity, such as weather and land quality are not considered. Thus, further research is needed to explore the relative efficiency of targeted and uniform taxes for reducing agricultural water pollution.

The objective of this paper is to evaluate the relative efficiency of targeted and uniform fertilizer-use taxes for reducing agricultural NO_3-N runoff in the Des Moines Watershed in Iowa, one of 14 watersheds in the Upper Mississippi River Basin. This objective is achieved by integrating economic and physical models. The economic model predicts farmers' crop choices, crop rotations, and conservation tillage adoption in the watershed. Predicted changes in crop choices, crop rotations, and tillage practices under the fertilizer-use taxes are then integrated into the physical model, Soil and Water Assessment Tool, to assess the level of NO_3-N runoff from the 9 subbasins in the watershed. In contrast to some previous studies, this study finds that the targeted fertilizer-use tax reduces the aggregate farm profit loss under the uniform fertilizer-use tax by up to 30 percent.

This paper is organized as follows. The next section presents a conceptual framework to evaluate the targeted and uniform taxes. The third section describes the empirical framework and its application to the Des Moines Watershed. The fourth section reports results. The fifth section evaluates the relative efficiency of two tax policies. The last section summarizes and concludes this study.

THE ANALYTICAL FRAMEWORK OF FERTILIZER-USE TAXES

Consider a watershed in which a particular water resource (e.g., a river) is polluted by NO_3-N runoff from agriculture. This watershed is divided into subbasins, denoted by i (i=1,2,...,I), based on a set of physical attributes. The physical attributes may include land slope, slope length, soil properties, distance to river, climate, and other geographic and topographic features. It is assumed that farmers in each subbasin face the same physical characteristics, and the same tax. Within each subbasin, cropland is distinguished by farming practices. The farming practices may include cropping patterns and cropping acreage. To capture the variation in farming practices within each subbasin, each subbasin is divided into "microunits", each of which is homogeneous in farming practices. Let A_{ij} be the area (in hectares) of microunit *j* in subbasin *i*. For simplicity, we assume that farmers have two alternative crops to produce: a polluting crop (PC) and non-polluting crop (NC). Farmers can gain higher profits from PC, but it requires nitrogen fertilizer for its growth. In contrast, profits for NC are lower than PC, but NC does not require nitrogen fertilizer. Let $\text{Prob}_{ij}(k)$ be the probability of crop *k* (*k* = PC, NC) being planted in microunit *j* in subbasin *i*. This probability is a function of profits for producing PC and NC:

$$\text{Prob}_{ij}(k) = \text{Prob}_{ij}\left[\pi_i^{\text{PC}}(N_i, \tau_i, w_i), \pi_i^{\text{NC}}(w_i)\right] \quad (1)$$

where π_i^{PC} and π_i^{NC} denote per-hectare profit function of PC and NC in microunit *j* in subbasin *i*, respectively. N_i is the application rate of nitrogen fertilizer, τ_i is the fertilizer-use tax, and w_i is an index of weather conditions in subbasin *i*. Then the aggregate farm profit and NO_3-N runoff for the watershed are represented by the followings.

$$\pi = \sum_{i=1}^{I} \pi^i = \sum_{i=1}^{I}\sum_{j=1}^{J_i}\left[\text{Prob}_{ij}(\text{PC}) \cdot \pi_i^{\text{PC}}(N_i, \tau_i, w_i) + \left(1 - \text{Prob}_{ij}(\text{PC})\right) \cdot \pi_i^{\text{NC}}(w_i)\right] \cdot A_{ij} \quad (2)$$

$$R = \sum_{i=1}^{I} R^i = \sum_{i=1}^{I}\sum_{j=1}^{J_i}\left[\text{Prob}_{ij}(\text{PC}) \cdot R_i^{\text{PC}}(N_i, \tau_i, w_i) + \left(1 - \text{Prob}_{ij}(\text{PC})\right) \cdot R_i^{\text{NC}}(w_i)\right] \cdot A_{ij} \quad (3)$$

where R_i^{PC} and R_i^{NC} are per-hectare NO3-N runoff from land planted to PC and NC in microunit *j* in subbasin *i*, respectively. It is assumed that $R_i^{\text{PC}} > R_i^{\text{NC}}$, $R_N^{\text{PC}} \geq 0$, and

$R_{NN}^{\mathrm{PC}} \geq 0$ where subscripts denote partial derivatives. The fertilizer-use tax affects π and R at both the intensive margin (changes in N_i) and the extensive margin (changes in $\mathrm{Prob}_{ij}(k)$). Below, we analyze how fertilizer-use tax affects farm profit and crop choice.

First, we analyze farmers' fertilizer-use decisions. Let $f^i(N_i, w_i)$ be per hectare production function of PC in subbasin *i*. This production function is state-contingent due to stochastic nature of w_i (and same for R^{ij}). It is assumed that $f_N^i \geq 0$ and $f_{NN}^i \leq 0$. Per hectare profit function for microunit *k* in the subbasin *i* is then given by

$$\pi_i^{\mathrm{PC}}(N_i, \tau_i) = pf^i(N_i) - (s + \tau_i)N_i \tag{4}$$

where $f^i(N_i) = E[f^i(N_i, w_i)]$ and $\pi_{ij}^{\mathrm{PC}}(N_i, \tau_i) = E[\pi_{ij}^{\mathrm{PC}}(N_i, \tau_i, w_i)]$. p is the price of PC, s is the unit price of nitrogen fertilizer, and τ_i is the rate of fertilizer-use tax for subbasin *i*. If farmers in the watershed are risk-neutral, the relevant decision is to choose the application rate of fertilizer to maximize the expected profit after the tax. The optimal rate of fertilizer application N_i^* solves the following first-order condition:

$$pf_N^i(N_i^*(\tau)) - s - \tau = 0 \tag{5}$$

The effect of a fertilizer-use tax on the optimal nitrogen application can be evaluated through comparative-static analysis. More specifically, taking derivative of N_i^* with respect to τ (use equation (5) and the implicit function theorem), we have

$$\frac{\partial N_i^*}{\partial \tau} = \frac{1}{pf_{NN}^i} < 0 \tag{6}$$

Because f_{NN}^{i} is negative, the sign of equation (6) is also negative. The effect of fertilizer-use tax on per hectare profit for PC is then given by

$$\frac{\partial \pi_i^{\mathrm{PC}}\left(N_i^*(\tau),\tau\right)}{\partial \tau_i} = \frac{\partial \pi_i^{\mathrm{PC}}}{\partial N_i} \cdot \left.\frac{\partial N_i}{\partial \tau_i}\right|_{N_i^*} + \left.\frac{\partial \pi_i^{\mathrm{PC}}}{\partial \tau_i}\right|_{N_i^*}$$

$$= 0 \cdot \frac{1}{pf_{NN}^{i}} - N_i^*$$

$$= -N_i^* \qquad (7)$$

Equation (6) and (7) indicate that the fertilizer-use tax always reduce both fertilizer application and per hectare profit for producing PC.

Next, we consider the effect of fertilizer-use tax on farmers' crop choice decisions. We assume that the probability of PC being planted in microunit k in subbasin i takes the following logit form[3]:

$$\mathrm{Prob}_{ij}(\mathrm{PC}) = \frac{1}{1+\exp\left(\pi_{ij}^{\mathrm{PC}}(N_i,\tau_i)\right)} \qquad (8)$$

where $\pi_{ij}^{\mathrm{PC}}(N_i,\tau_i)$ is given by equation (4). The probability that NC is planted in microunit j in subbasin i is simply $1-\mathrm{Prob}_{ij}(\mathrm{PC})$. Then, the effect of fertilizer-use tax on the probability of choosing PC is given by differentiating equation (8) with respect to τ_i:

$$\frac{\partial \mathrm{Prob}_{ij}(\mathrm{PC})}{\partial \tau_i} = P_{ij}^2 \cdot \frac{\partial \pi_i^{\mathrm{PC}}}{\partial \tau_i}$$

$$= -N_i^* \cdot P_{ij}^2 < 0 \qquad (9)$$

where $P_{ij} = \text{Prob}_{ij}(\text{PC})$. Because the logit probability is always positive and less than one ($0 < P_{ij} < 1$), the sign of equation (9) is negative. That is, the fertilizer-use tax always reduce the probability of choosing PC, and increase simultaneously the probability of choosing NC ($\partial \text{Prob}_{ij}(\text{NC})/\partial \tau_i = -\partial \text{Prob}_{ij}(\text{PC})/\partial \tau_i > 0$).

The Effect of Fertilizer-Use Tax on Subbasin Farm Profit and NO_3-N Runoff

We now consider the effect of fertilizer-use tax on farm profit and NO_3-N runoff for subbasin *i*. The effect of tax on farm profit can be given by differentiating a part of equation (2) with respect to τ_i

$$\frac{\partial \pi^i}{\partial \tau_i} = \pi^i_\tau = \sum_{j=1}^{J_i} \left[P_{ij} \cdot \frac{\partial \pi_{ij}^{\text{PC}}}{\partial \tau_i} + \frac{\partial P_{ij}}{\partial \tau_i} \cdot \pi_{ij}^{\text{PC}} - \frac{\partial P_{ij}}{\partial \tau_i} \cdot \pi_{ij}^{\text{NC}} \right] \cdot A_{ij}$$

$$= \sum_{j=1}^{J_i} \left[-N_i^* P_{ij} - N_i^* P_{ij}^2 \cdot \pi_{ij}^{\text{PC}} + N_i^* P_{ij}^2 \cdot \pi_{ij}^{\text{NC}} \right] \cdot A_{ij}$$

$$= \sum_{j=1}^{J_i} \left[N_i^* P_{ij}^2 \left(\pi_{ij}^{\text{NC}} - \pi_{ij}^{\text{PC}} \right) - N_i^* P_{ij} \right] \cdot A_{ij} < 0 \tag{10}$$

Equation (10) indicates that the effect of fertilizer-use tax can be decomposed into two components. The first term in parenthesis is changes in crop choice (the extensive margin effect) in microunit *j* in subbasin *i*. The second term in parenthesis is changes in the application of nitrogen fertilizer in the same microunit. Because it is assumed that

$\pi_{ij}^{\text{PC}} > \pi_{ij}^{\text{NC}}$, the sign of both term is negative, implying that the fertilizer-use tax always reduces subbasin *i*'s farm profit at both intensive and extensive margin.

Next, we evaluate the effect of fertilizer-use tax on NO_3-N runoff from subbasin *i*. By differentiating a part of equation (3) with respect to τ_i, we have

$$\frac{\partial R^i}{\partial \tau_i} = R_\tau^i = \sum_{j=1}^{J_i} \left[P_{ij} \cdot \frac{\partial R_{ij}^{\text{PC}}}{\partial N_i} \frac{\partial N_i}{\partial \tau_i} + \frac{\partial P_{ij}}{\partial \tau_i} \cdot R_{ij}^{\text{PC}} - \frac{\partial P_{ij}}{\partial \tau_i} \cdot R_{ij}^{\text{NC}} \right] \cdot A_{ij}$$

$$= \sum_{j=1}^{J_i} \left[N_i^* P_{ij}^2 \left(R_{ij}^{\text{NC}} - R_{ij}^{\text{PC}} \right) - R_N^{\text{PC}} \cdot \frac{1}{pf_{NN}^i} \right] \cdot A_{ij} < 0 \qquad (11)$$

As is the case with the effect on farm profit in equation (10), the first term in parenthesis is the change in NO_3-N runoff at the extensive margin in microunit *k* in subbasin *i*. The second term in parenthesis indicates the change in the application of nitrogen fertilizer in the same microunit. Given assumptions that $R_{ij}^{\text{PC}} > R_{ij}^{\text{NC}}$, $R_N^{\text{PC}} > 0$, and $f_{NN}^i < 0$, the sign of both term is negative. Thus, the fertilizer-use tax always reduces NO_3-N runoff at both intensive and extensive margin.

The Targeted Fertilizer-Use Tax

Based on discussions above, we derive the optimal fertilizer-use tax for reducing NO_3-N runoff in the watershed. Suppose that the policymaker does not know the optimal level of NO_3-N runoff, but has the runoff reduction target (e.g. 30 percent reduction from the current level of runoff). Then the policymaker's objective is to find the tax rates that maximize the aggregate farm profit as well as achieve runoff reduction target. This objective is represented by the following constrained maximization problem.

$$\underset{\tau_i}{\text{Max.}} \sum_{i=1}^{I} \pi^i\left(\pi_{ij}^{\text{PC}}, \pi_{ij}^{\text{NC}}, P_{ij}, A_{ij}\right) \quad \text{s.t.} \quad \frac{\overline{R} - \sum_i R^i\left(R_{ij}^{\text{PC}}, R_{ij}^{\text{NC}}, P_{ij}, A_{ij}\right)}{\overline{R}} = T, \quad \text{for all } i \tag{12}$$

where $\overline{R}$ is the initial level of NO_3-N runoff from the watershed (i.e. runoff before the tax is levied), and T is the targeted level of NO_3-N runoff reduction, $0 \leq T \leq 1$. $T = 0$ indicates no runoff reduction, and $T = 1$ indicates complete reduction of runoff from the watershed. The Lagrangian corresponding to this constrained maximization problem is:

$$L = \sum_{i=1}^{I} \pi^i\left(\pi_{ij}^{\text{PC}}, \pi_{ij}^{\text{NC}}, P_{ij}, A_{ij}\right) - \lambda\left[\frac{\overline{R} - \sum_i R^i\left(R_{ij}^{\text{PC}}, R_{ij}^{\text{NC}}, P_{ij}, A_{ij}\right)}{\overline{R}} - T\right] \tag{13}$$

Assuming an interior solution exists, the policymaker solves the following first-order condition

$$\frac{\partial L}{\partial \tau_i} = \frac{\partial \pi^i}{\partial \tau_i} - \lambda\left[\frac{\partial R^i / \partial \tau_i}{\overline{R}}\right]$$

$$= \pi_\tau^i - \lambda \cdot \frac{R_\tau^i}{\overline{R}}, \quad \text{for all } i \tag{14}$$

where π_τ^i and R_τ^i are given by equations (10) and (11), respectively. From equation (14), we obtain the following rule for the optimal targeted tax

$$\frac{\pi_\tau^1}{R_\tau^1} = \frac{\pi_\tau^2}{R_\tau^2} = \ldots = \frac{\pi_\tau^I}{R_\tau^I} \tag{15}$$

Equation (15) suggests that the fertilizer-use tax rates should be differentiated across subbasins based on the marginal profit and marginal runoff of nitrogen fertilizer (i.e. π_τ^i

and R_{τ}^{i}). Thus, under spatial conditions, the least cost solution for reducing NO_3-N runoff can be achieved by the targeted tax.

The Uniform Fertilizer-Use Tax

The targeted fertilizer-use tax, although theoretically capable of reducing NO_3-N at the least cost, may be difficult to implement in reality. Optimal tax rates, derived from equation (15), requires the policymaker to gather much local information on farm profit and NO_3-N runoff for each subbasin in the watershed. Furthermore, the amount of fertilizer applied in each subbasin needs to be monitored to prevent the potential resale problem[4]. These costs could be reduced by applying a single tax rate (i.e. uniform tax) to the entire watershed.

Under the uniform fertilizer-use tax, the policymaker's objective is to find a single tax rate that maximizes the aggregate farm profits and reduces NO_3-N runoff by T

$$\underset{\tau}{\text{Max.}} \sum_{i=1}^{I} \pi^{i}\left(\pi_{ij}^{\text{PC}}, \pi_{ij}^{\text{NC}}, P_{ij}, A_{ij}\right) \quad \text{s.t.} \quad \frac{\overline{R} - \sum_{i} R^{i}\left(R_{ij}^{\text{PC}}, R_{ij}^{\text{NC}}, P_{ij}, A_{ij}\right)}{\overline{R}} = T, \quad \text{for all } i \qquad (16)$$

Under the uniform policy, finding the tax rate is straightforward. Optimal tax rate can be derived directly from the constraint in equation (16). The optimal tax rate τ^{*} which reduces runoff by T under this policy is

$$\sum_{i=1}^{I} R^{i}\left[R_{ij}^{\text{PC}}\left(\tau^{*}\right), R_{ij}^{\text{NC}}\left(\tau^{*}\right), P_{ij}\left(\tau^{*}\right), A_{ij}\right] = (1-T)\overline{R} \qquad (17)$$

Although equation (15) and (17) suggest that the optimal uniform tax τ^* attains the least cost solution under homogeneous conditions (i.e. B_τ^i and R_τ^i are identical across subbasins), it may not be likely in reality. In other words, the uniform tax is always less efficient than targeted tax under the spatially heterogeneous watershed. In general, the characteristics of NPS pollution vary by subbasins due to the great variety of farming practices, land forms, climate, and hydrologic characteristics found across even relatively small areas (Ribaudo et al 1999). Thus, even if the same amount of nitrogen fertilizer is applied to the entire watershed, resulting NO_3-N runoff will be different across subbasins. The relative efficiency of targeted and the uniform taxes therefore depends critically on the degree of spatial heterogeneity in the watershed.

Thus far, we examined optimal fertilizer-use tax under the targeted and uniform policies for reducing NO_3-N runoff from agriculture. We show that although the targeted fertilizer-use tax can reduce NO_3-N runoff at the least cost, it may be difficult to implement because of information requirements. In contrast, the uniform tax is much easier to implement because it relaxes considerably information requirements. However, the uniform tax is always less efficient than the targeted tax if the watershed is spatially heterogeneous. A relevant question is whether there is substantial efficiency gain from the targeted policy. To address empirically this question, the relative efficiency of targeted and uniform taxes needs to be empirically evaluated.

THE EMPIRICAL APPLICATION TO THE DES MOINES WATERSHED

Description of the Watershed

An empirical analysis of the relative efficiency of targeted and uniform taxes is applied to the Des Moines Watershed in Iowa (figure 4.1), encompassing 3.6 million hectares. This watershed accounts for about 8 percent of the Upper Mississippi River Basin (MRB). The elevation of the watershed ranges between 146 and 595 meters. Topography is flat, with an average slope of 1.5 percent. This watershed consists of two major tributary channels, those of the Raccoon and Des Moines. The watershed has a typical subhumid, continental climate. Data from Iowa Environmental Mesonet reports that mean monthly temperatures range from -9.8 °C in January to 24.9 °C in July. Mean monthly precipitation ranges from 16 millimeters during February to 216 millimeters during July for the period of 1988 and 1999. Mean annual precipitation for those two years is 881 millimeters. In this watershed, much of the precipitation is produced by thunderstorms in spring and summer months (Boyd 2001). Precipitation is generally high in the midstream area, and low in the upper and lower areas of the watershed.

The level of NO_3-N water pollution in this watershed is particularly high compared with other watersheds in the Upper MRB. Evidence shows that NO_3-N concentrations in the public water supply of the Des Moines often exceeds the MCL of 10 mg/L from April to July, the period after fertilizers are applied and when storm runoff is frequent (USGS 2003). This watershed contains about 3 million hectares of agricultural land, accounting for 83 percent of the total land. Much of land upstream is planted to row crops (corn and soybean) and heavily fertilized. The most common cropping practices for row crops is corn-soybean rotation under conventional tillage and under conservation tillage, accounting for 22 and 43 percent and in the watershed, respectively[5] (table 4.1). Other cropland is mostly used for producing hay and other crops (e.g. winter wheat). Major non-agricultural land uses in the watershed include urban, forest, and wetland.

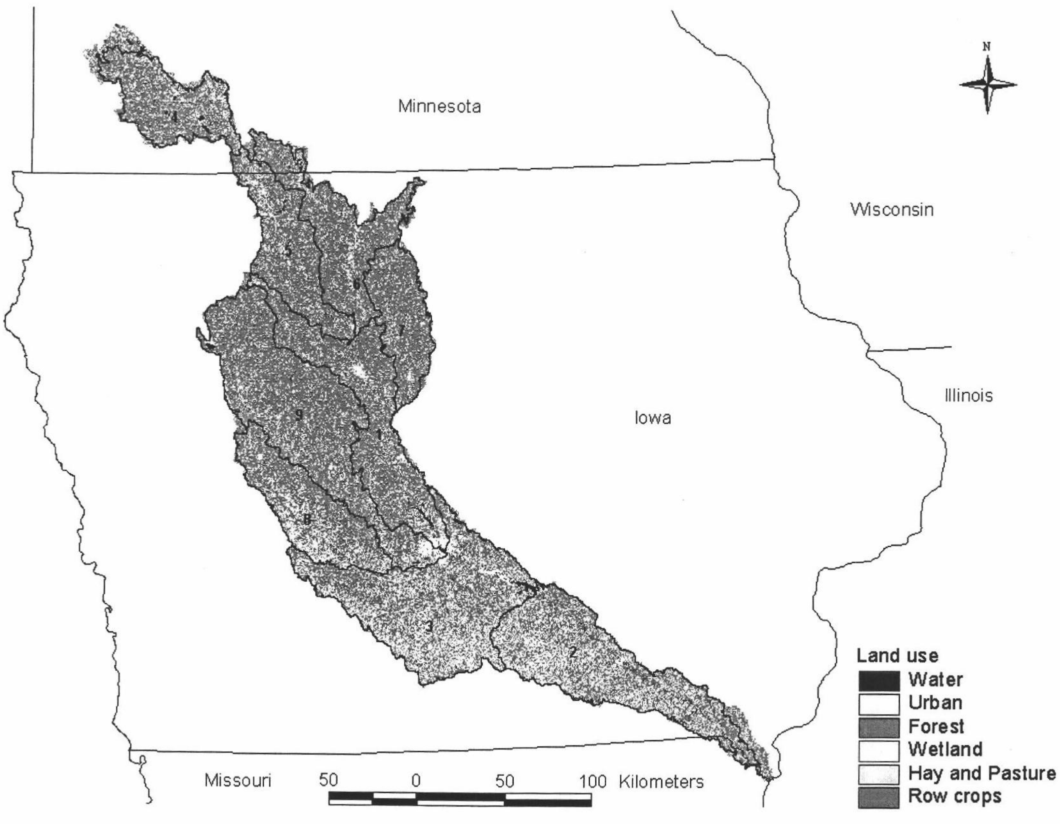

Figure 4.1 Major Land Use in the Des Moines Watershed

Table 4.1 Major Land Use in the Des Moines Watershed[a]

Land use	Area (hectare)	Share (%)
Open Water	42,482	1.2
Wetland	66,237	1.8
Forest	412,879	11.2
Urban	79,212	2.1
Agriculture		83.8
Corn-soybean - conventional tillage[b]	827,744	22.4
Corn-soybean - conservation tillage[c]	1,598,427	43.3
Continuous corn - conventional tillage	607	0.0
Continuous corn - conservation tillage	1,821	0.1
Hay and Other crop	522,933	14.2
CRP	141,154	3.8
Total	3,693,496	100.0

[a] Double ruled rows indicate a breakdown of agriculture/pasture.
[b] Including soybean-corn rotation under conventional tillage.
[c] Including soybean-corn rotation under conservation tillage.

The Integrated Modeling Framework

We develop the integrated modeling framework to evaluate the relative efficiency of targeted and uniform fertilizer-use taxes in the Des Moines Watershed. The structure of the integrated modeling framework is presented in figure 4.2. The framework is based upon the Natural Resource Inventories (NRI), conducted by the Natural Resource Conservation Service (NRCS). The NRI is a scientifically based, longitudinal panel survey of the Nation's soil, water, and related resources, designed to assess conditions and trends every five years (NRCS 2000). The NRI contains information on nearly 800,000 sample sites across the continental United States. At each site, information on nearly 200 attributes, including cropping history, soil properties, and agricultural land management practices, are collected. The NRIs also contain an expansion factor, which indicates the acreage each site represents. Thus, the total acreage in the basin can be calculated by summing up the expansion factors for all sites in the basin. In the Des Moines Watershed, there are a total of 8,838 sites and, among these sites, 4,911 sites are used for agriculture and Conservation Reserve Program (CRP) in 1997[6]. Using the 1982, 1987, 1992, and 1997 NRIs and other site-specific information about production practices and physical characteristics, the economic models are estimated to predict agricultural land use before and after a policy change in the Des Moines Watershed.

Changes in land use predicted by the economic models are then used as inputs for the physical model to predict NO_3-N runoff in the watershed before and after a policy is implemented. 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 detail both the economic and physical components of the framework.

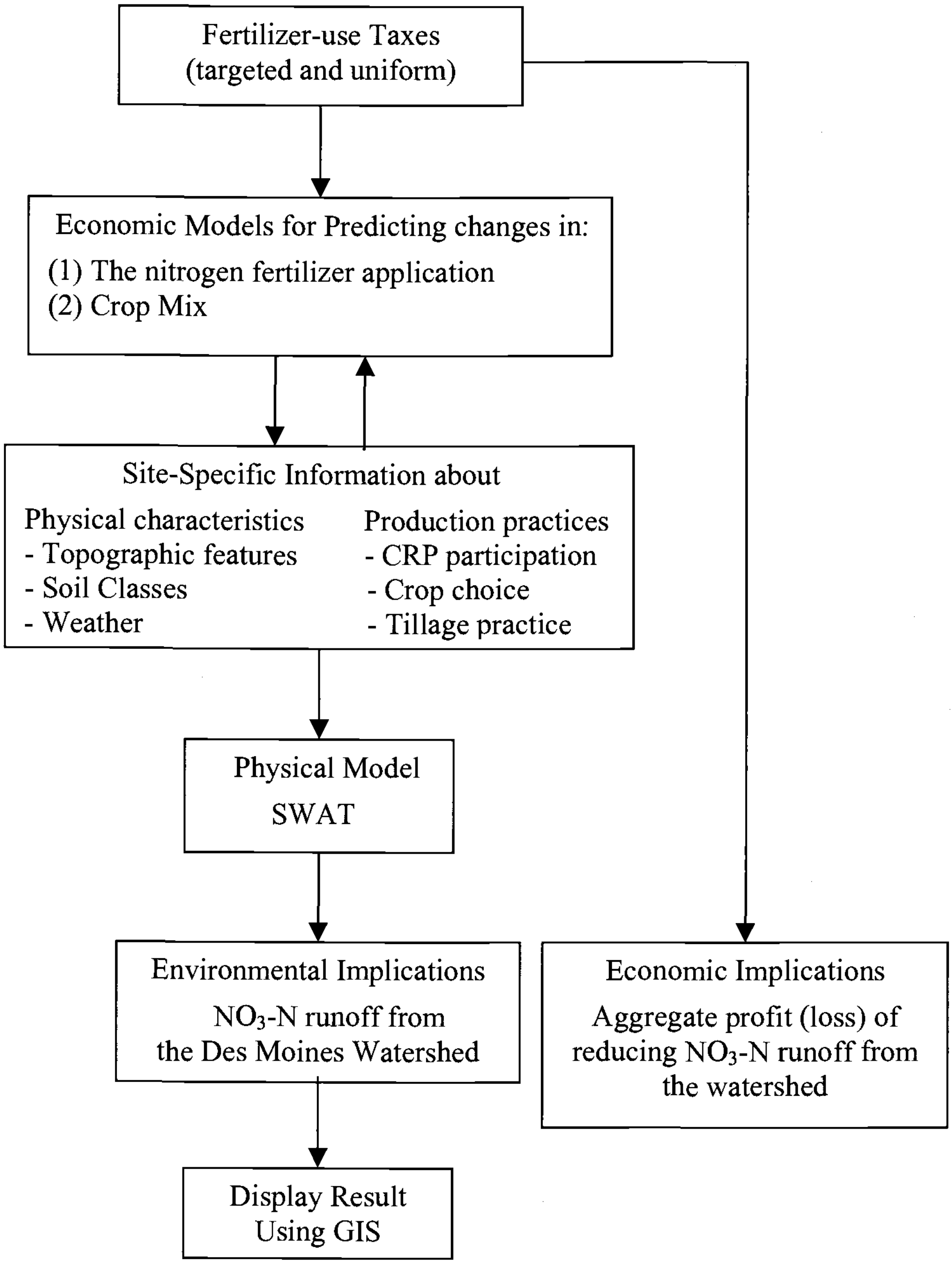

Figure 4.2 The Integrated Modeling Framework

The Economic Models

The objective of the economic models is to estimate the effect of fertilizer-use tax at both intensive and extensive margin in the Des Moines Watershed. The intensive margin effect is captured by estimating farmers' fertilizer application adjustments under the tax. To this end, we use the own price elasticities of nitrogen fertilizer use reported in the literature. Denabaly and Vroomen (1993) develop a dynamic model of corn nutrient demands in the U.S. Midwest. They estimate that the own price elasticities of nitrogen applied in the region is -0.21. Applying this own price elasticities to the base rate of nitrogen application, the nitrogen application rate under the tax rate τ is estimated by $N(\tau) = N_0(1+\tau)^{-0.21}$, where N_0 is the base application rate of 201 Kg ha^{-1}. N_0 is derived following suggestions from Jerome Neppel at the Soil and Water Conservation Society and data from Iowa agricultural experimental station[7].

To estimate the extensive margin effect, the three econometric models are developed. Those three models predict farmers' decisions regarding: (1) CRP participation; (2) crop choice; and (3) tillage practice. More specifically, the CRP model predicts farmers' decisions as to whether or not to participate in the CRP program at each NRI site in the Des Moines Watershed. The crop choice model predicts farmers' choice of crop at each NRI site (corn, soybean, hay or other crop). The tillage model predicts farmers' choice of tillage practices, either conventional or conservation, at each NRI site. These econometric models are specified as logistic functional forms to predict the probability of choosing each of the land use options at each NRI site. The alternative with the highest probability is assumed to be the choice at the site. For example, a site is assumed to enroll in CRP if the predicted probability of participating the program is greater than the probability of not participating the program. These econometric models have been documented and published in Tanaka and Wu (2003a) and Wu et al (2004).

The three logistic models are used in the following order. First, the CRP model is used to predict which site is enrolled in the CRP. Second, the crop choice model is applied to the sites not participating in the CRP. The crop choice model assigns one of the crops (corn, soybean, hay, and other crop) to each of the NRI sites for the period of 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).

The Physical Model

This study uses Soil and Water Assessment Tool (SWAT) to estimate the level of NO_3-N runoff from the Des Moines Watershed. SWAT is developed by the USDA Agricultural Research Service (ARS) to simulate water balance in a large scale watershed for a long period of time (up to 100 years). SWAT can predict the impact of crop practices on water, sediment, and agricultural chemical movements in large, complex watersheds with varying soils, land use, and management conditions over a long period of time (Neitsch et al 2002). Because SWAT is a physically based, no regression equation is necessary to predict the relationship between input and output variables. Instead, SWAT requires wide-ranging detailed information including topography, soil properties, land management scenarios, and weather in the watershed.

SWAT uses topographic information to determine watershed and subbasin (subwatershed) boundaries and to digitize the streams (line representation of accumulated perennial water flow over the soil surface) in the watershed. This study uses 1-degree Digital Elevation Model (DEM) data provided by the USGS[8]. To enhance the accuracy of this process, the National Hydrography Dataset (NHD), digitized stream network developed by the USGS and EPA, is used as a complement to the DEM. As a result, a total of 9 subbasins are delineated by the hydrologic component of SWAT.

SWAT requires a geographical representation of soil distribution, which is used to define the soil's chemical and physical properties to simulate the watershed. The soil coverage is prepared from the State Soil Geographic (STATSGO) digital soil association map, developed by the NRCS. SWAT GIS interface (called AVSWAT) automatically chooses the most dominant soil class from STATSGO map and extract necessary information from a relational database. Extracted information includes texture, bulk density, saturated conductivity, available water capacity, organic carbon, and others. The dominant soil types in the watershed are presented in figure 4.3.

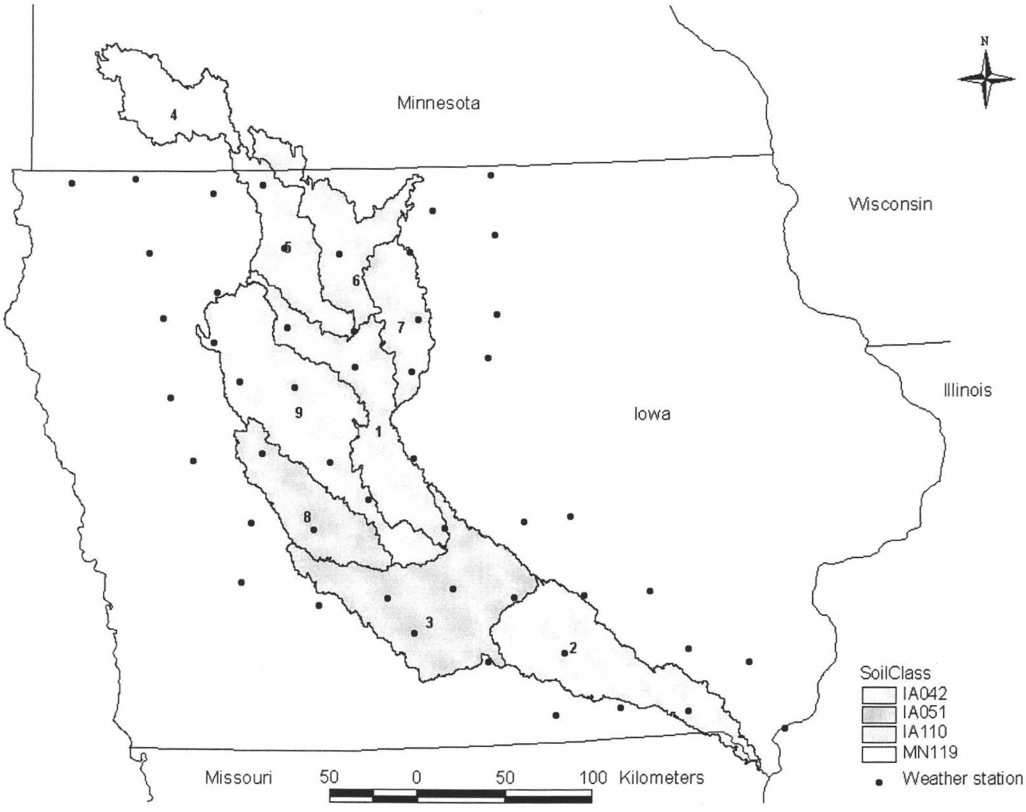

Figure 4.3 Dominant Soil Types and Weather Stations in the Des Moines Watershed

Primary land use information is derived from the National Land Cover Dataset (NLCD) provided by the USGS. The NLCD is a 30-meter resolution raster land cover for the entire United States. The NLCD presents detailed land use for agriculture (row-crop and hay), forest, wetland, water, urban, and other land uses (figure 4.1). Land planted to row crops (corn and soybean) is further classified by four major cropping systems (corn-soybean rotation and continuous corn under conventional and conservation tillage) in the watershed. This classification is derived from the baseline estimates of the economic model.

The land management schedules describe management practices for each land use in the watershed (e.g. timing and amount of fertilizer application). The scenario for each land use can be either different across subbasins or identical in the entire watershed. In this study, we use the same management scenario for each land use. Detailed description of each agricultural land use management scenario is presented in table 4.2. Although many types of tillage operations are defined as conservation tillage, this study uses no-till as a representative. No-till is a method of farming where the soil is left undisturbed from the harvest of one crop to the beginning of next growing season. Thus, soil disturbance occurs only when fertilizer is applied before growing season, and crop is harvested. Non-agricultural land uses follow SWAT default land management scenarios.

The weather variables required for SWAT simulations are the daily values of maximum and minimum air temperature, precipitation, solar radiation, wind speed, and relative humidity. We obtained historical observations of the daily temperatures and precipitation from Iowa Environmental Mesonet. AVSWAT gathers weather data reported from 60 weather stations in and around the Des Moines Watershed and chooses the variables reported from the nearest station for each subbasin (figure 4.3). The daily values of solar radiation, wind speed, and relative humidity are simulated using SWAT built-in random weather generator.

Table 4.2 Management Scenarios for Agricultural Land Use[a]

Land use	Management Scenario
Corn-Soybean / conventional tillage	Two-year rotation of corn-soybean production. In spring of the first year, the land is tandem disk plowed. Then, 74 Kg per hectare of anhydrous ammonia is applied shortly before planting corn in late April. Corn is harvested in mid-October and the soil is chisel plowed. In the second year, secondary tillage (tandem disk plow) is operated shortly before planting soybean in mid-May. Soybean is harvested in early October. In mid-November, 94 Kg per hectare of preplant anhydrous ammonia is applied.
Corn-Soybean / no-till	Basic operations are same as corn-soybean rotation under conventional tillage. Under no-till scenario, however, corn and soybean are grown without any tillage operation. The only soil disturbance under no-till operation is fertilizer injection after harvesting soybean and before planting corn.
Continuous corn / conventional tillage	Single year operation of corn production. In spring, the land is tandem disk plowed. Then, 74 Kg per hectare of anhydrous ammonia is applied before planting corn in late April. Corn is harvested in mid-October and the soil was chisel plowed. In mid-November, 94 Kg per hectare of preplant anhydrous ammonia is applied
Continuous corn / no-till	Basic operations are same as the continuous corn production under conventional tillage, besides that no tillage operation is conducted to minimize the soil disturbance
Hay	5-year operation. In the first year, bermudagrass is planted in mid-May. Grazing operations are held three times in each year. No fertilizer is applied.

[a] Other land uses (forest, wetland, and urban) follow SWAT's default management schedule.

[b] land planted to other crops and adopting to CRP follows hay.

RESULTS

The Effect of Uniform Fertilizer-Use Tax on Agricultural Land use

Using the economic models, we estimate the effect of the fertilizer-use taxes on the probabilities of adopting alternative cropping systems. (corn-soybean rotation and under conventional and conservation tillage, hay, and other crop). The estimation is applied to more than 4,900 NRI sites in the Des Moines Watershed. Some independent variables in the logistic models are "policy variables" because they are affected by certain policies such as input-use taxes. In this study, the effect of the fertilizer-use tax is simulated by increasing the price of fertilizer in the crop choice model, holding other independent variables constant. Using increased fertilizer price, the probabilities of adopting alternative cropping systems are re-estimated for each NRI site in the watershed. Using re-estimated probabilities, changes in major cropping acreages are derived.

Figure 4.4 presents the simulated effects of the nitrogen fertilizer-use tax on major cropping systems: corn soybean rotation under conventional tillage, corn-soybean rotation under conservation tillage, and hay, and other crop. Figure 4.4 does not include continuous corn and continuous soybean because these acreages are too small to be displayed in the figure. Under the fertilizer-use tax, corn-soybean rotation acreages decline, while hay and other crop acreages increase simultaneously as the tax rate increases. This is consistent with the fact that nitrogen fertilizer is an essential input for corn and soybean, whereas it is not for hay and other crop. Among corn-soybean rotations, conventional tillage is more responsive to the tax than conservation tillage At the tax rate of 200 percent, conventional tillage decreases by nearly 40 percent, whereas conservation tillage decreases by only 18 percent. This can be explained by tillage intensity. Nitrogen fertilizer-use efficiency is highly affected by tillage intensity through its impact on water entry, retention, and subsequent N-cycling process in the soil profile (Bakhsh et al 2000). This efficiency is generally higher under conservation tillage (e.g. no-till) than conventional tillage (e.g. chisel-plowing). Because fertilizers are used more efficiently, reduced fertilizer use under conservation tillage has smaller impacts on crop yields and thus farm profits than conventional tillage. Overall, the acreage responses of corn-soybean rotations are quite elastic. Thus the fertilizer-use tax is effective in promoting farmers to convert from "polluting" crops to "non-polluting" crops. Although figure 4.4 indicates high tax rates for reducing polluting crop acreages significantly, this is consistent with previous studies analyzing the tax effect on farmers' fertilizer applications (for example, Huang and Lantin 1993 and Whittaker et al 2004).

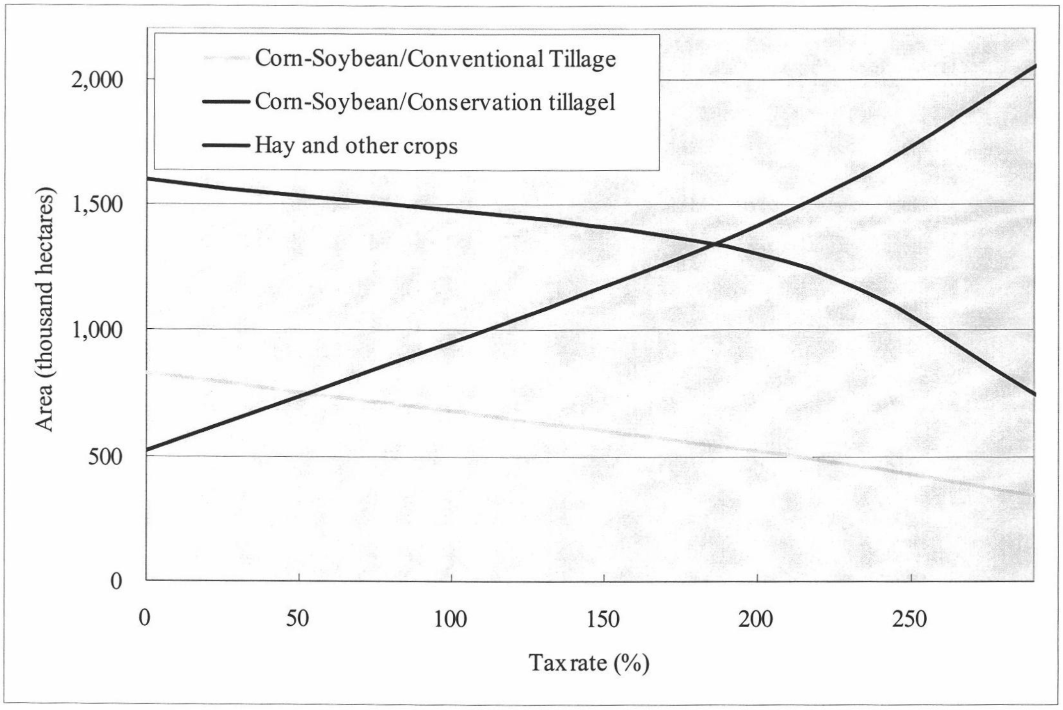

Figure 4.4 Acreage Response of the Major Agricultural Productions Under the Uniform Fertilizer-Use Tax[a]

SWAT Model Validation and Predicted NO_3-N Runoff

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 4.5). 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.

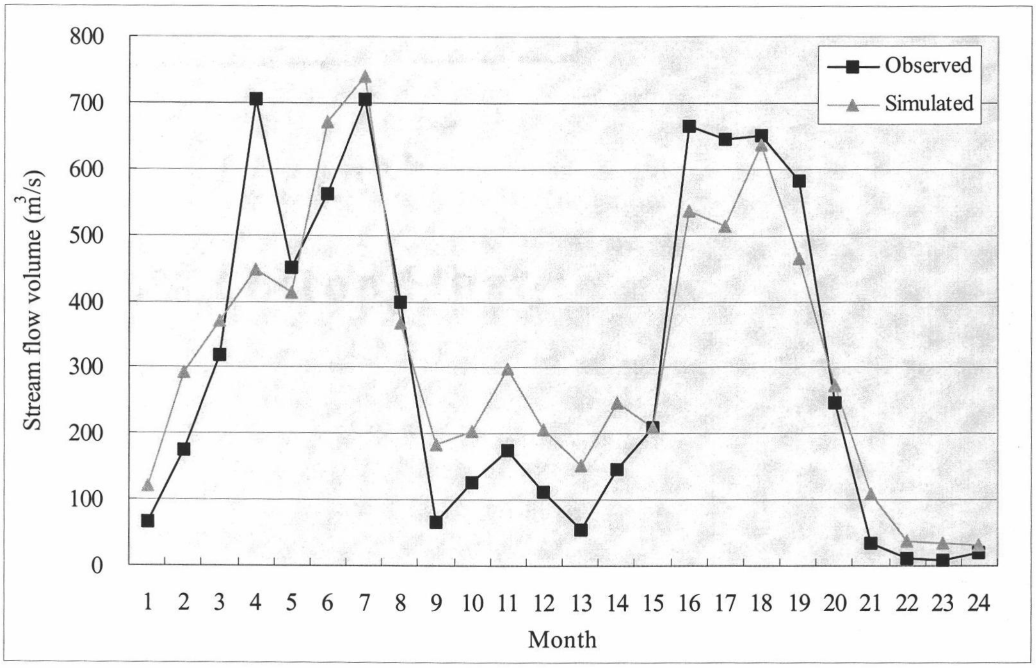

Figure 4.5 Simulated and Observed Streamflow in the Des Moines River at Ottumwa, Iowa 1998-99 ($R^2 = 0.88$)

Table 4.3 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) reports that NO_3-N runoff from row crops is 30 to 50 times higher than from the perennial crops.

Table 4.3 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 1. As figure 4.1 indicates, row crops are intensively planted in this subbasin. In addition, annual precipitation in subbasin 1 is higher than any other subbasins in the watershed. In contrast, the lowest NO_3-N runoff is predicted in the subbasin 2, 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.

Table 4.3 Predicted NO_3-N Runoff Under Different Agricultural Land Use in the Des Moines Watershed (Kg ha^{-1})

Land use	Subbasin 1	2	3	4	5	6	7	8	9	Watershed average
Corn-soybean - CT	3.9	1.2	2.3	3.5	2.9	2.3	3.0	2.6	2.4	2.7
Corn-soybean - NT	1.4	0.6	0.9	1.1	0.9	1.3	1.1	1.1	1.1	1.0
Continuous corn - CT	5.8	1.7	4.3	6.6	4.6	4.2	4.2	4.4	4.1	4.4
Continuous corn - NT	3.2	0.9	2.3	2.9	1.5	2.7	1.9	1.8	2.2	2.2
Hay and pasture	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1
Subbasin average	2.9	0.9	2.0	2.8	2.0	2.1	2.1	2.0	2.0	2.1

[a] CT and NT denote conventional tillage and no-till respectively.

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.

POLICY SIMULATIONS AND DISCUSSIONS

Using results from the economic and physical models, we now evaluate the effect of the fertilizer-use tax on farm profits and NO_3-N runoff in the Des Moines Watershed. Under the uniform tax, the aggregate farm profit in the watershed is estimated by:

$$\pi = \sum_{i=1}^{I} \sum_{j=1}^{J_i} \sum_{k=1}^{K} \text{Prob}(k \mid \tau)_{ij} \cdot \pi_k(\tau) \cdot xfactor_{ij} \tag{18}$$

where $\text{Prob}(k \mid \tau)_{ij}$ is the probability of choosing crop *k* at NRI site *j* in subbasin *i* at the tax rate τ. $xfactor_{ij}$ is an expansion factor which indicates the hectares site *j* represents, and $\pi_k(\tau)$ is per hectare profit for crop *k* at the tax rate τ [9]. The probabilities of growing alternative crops at each site are estimated from the economic models. Per hectare profits for alternative crops are calculated by $p_k y_k - c_k$, where p_k is the crop *k*'s price, y_k is the per hectare yield of crop *k*, and c_k is per hectare cost of producing crop *k*. All crop prices and per hectare yields for soybean and hay are obtained from Agricultural Statistics 2000. Per hectare production costs are adapted from the estimates by Duffy (2000). Because corn yield is influenced by the fertilizer application rate, per hectare yields for corn are calculated using the yield response function developed by Stecker et al (1995). They estimate the quadratic models of yield responses to nitrogen fertilizer for continuous corn and corn-soybean rotation. The yields of soybean and hay are assumed not to be affected by the fertilizer-use tax. The total NO_3-N runoff in the watershed is estimated by:

$$R = \sum_{i=1}^{I} \sum_{j=1}^{J_i} \sum_{k=1}^{K} \text{Prob}(k \mid \tau)_{ij} \cdot R_{ik}(\tau) \cdot xfactor_{ij} \tag{19}$$

where $R_{ik}(\tau)$ is the per hectare NO_3-N runoff from crop *k*'s land in subbasin *i*.

Figure 4.6 illustrates the total NO_3-N runoff under the uniform fertilizer-tax in the Des Moines Watershed. Overall, the total NO_3-N runoff from the watershed is quite responsive to the fertilizer-use tax. It is particularly responsive when the tax rate is more than 150 percent. When the tax rate is 250 percent, the total runoff from the subbasin is reduce by more than 70 percent. The tax rates necessary to reduce NO_3-N runoff by 10 to 50 percent is reported in table 4.4.

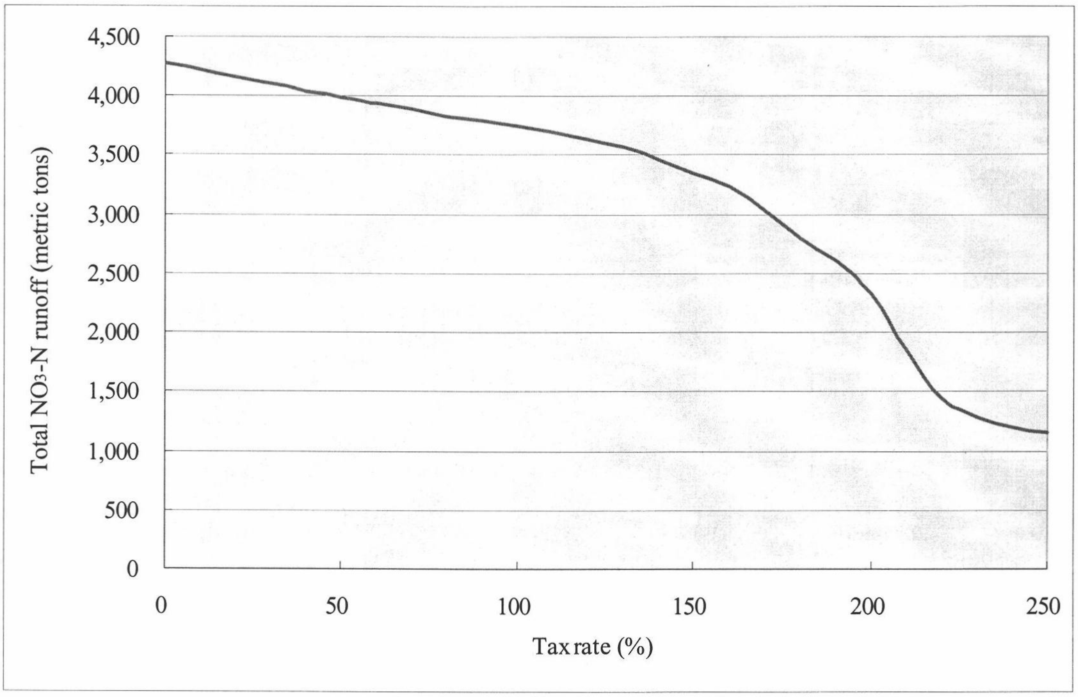

Figure 4.6 Total NO_3-N Runoff Under the Uniform Fertilizer-Use Tax in the Des Moines Watershed

Under the targeted policy, the tax rates must be differentiated for each of 9 subbasins which achieve the reduction target at the least cost (e.g. 30 percent runoff reduction while minimizing the aggregated profit loss). Figure 4.7 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. Based on derivation above, the marginal profit loss curves ML_i for 9 subbasins in the watershed are estimated by:

$$\overline{\pi}^i - \pi^i(\tau_i) = \overline{\pi}^i - \sum_{j=1}^{J_i}\sum_{k=1}^{K} \text{Prob}(k \mid \tau_i)_{ij} \cdot \pi_{ik}(\tau_i) \cdot xfactor_{ij} \tag{20}$$

where $\overline{\pi}^i$ is the aggregate farm profit at the baseline (i.e. before tax is levied). The curves in the lower figure, S_i for each of subbasins are estimated by:

$$\overline{R}^i - R^i(\tau_i) = \overline{R}^i - \sum_{j=1}^{J_i}\sum_{k=1}^{K} \text{Prob}(k \mid \tau_i)_{ij} \cdot R_{ik}(\tau_i) \cdot xfactor_{ij} \tag{21}$$

where $\overline{R}^i$ is the initial level of NO_3-N runoff from subbasin i.

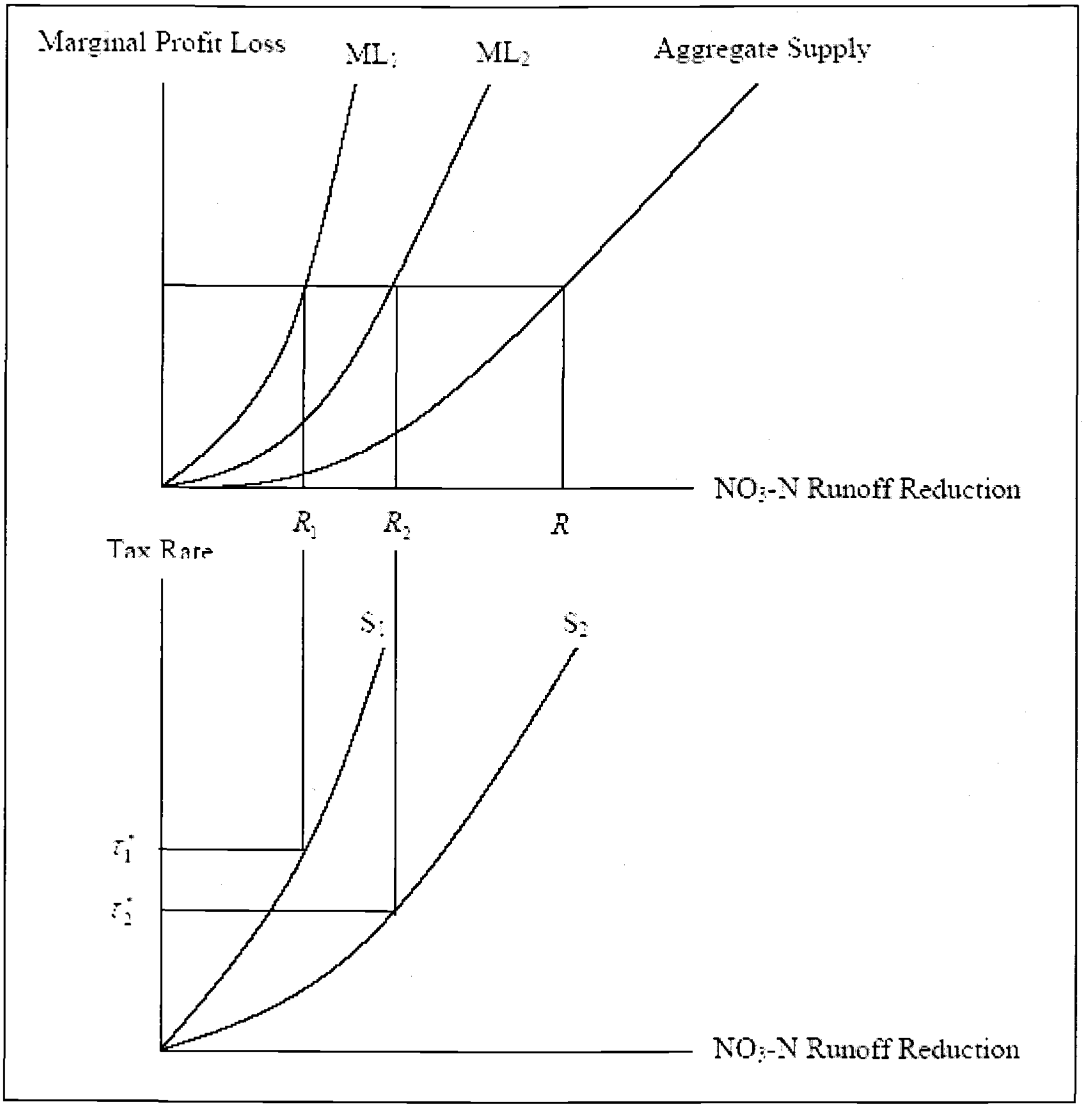

Figure 4.7 Optimal Tax Rates Under the Targeted Fertilizer-Use Tax

Table 4.4 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 1, and the lowest for subbasin 2 to achieve each of NO_3-N runoff reduction targets. SWAT model predicts that subbasin 1 has the highest NO_3-N runoff potential, and thus more likely to contribute to water pollution than any other subbasins in the watershed. In contrast, subbasin 2 is predicted to have the lowest NO_3-N runoff potential, 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 4.4 Optimal Tax Rates Under the Targeted and Uniform Tax Polices

		NO3-N runoff reduction from the watershed (%)				
		10	20	30	40	50
Uniform tax (%)		83	149	173	194	205
Targeted tax (%)	Subbasin					
	1	92	164	195	214	232
	2	51	92	117	137	143
	3	57	102	126	141	156
	4	88	163	191	212	231
	5	67	120	140	166	180
	6	66	118	142	160	176
	7	84	151	183	202	218
	8	63	113	138	153	169
	9	75	135	165	180	198

Table 4.5 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 2 and 3 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 4.5 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 (%)
1	540,703	641,795	15.8	136,932	218,327	37.3
2	710,933	233,882	-204.0	74,224	27,711	-167.9
3	981,213	359,140	-173.2	136,039	55,735	-144.1
4	1,049,321	1,366,796	23.2	428,496	572,607	25.2
5	506,758	297,157	-70.5	126,231	81,437	-55.0
6	690,613	463,583	-49.0	119,946	87,333	-37.3
7	448,661	503,115	10.8	33,262	76,607	56.6
8	663,541	334,561	-98.3	79,371	28,269	-180.8
9	817,761	749,916	-9.0	103,256	89,626	-15.2
Watershed	6,409,505	4,949,945	-29.5	1,237,759	1,237,651	< 0.01

Finally, figure 4.8 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.

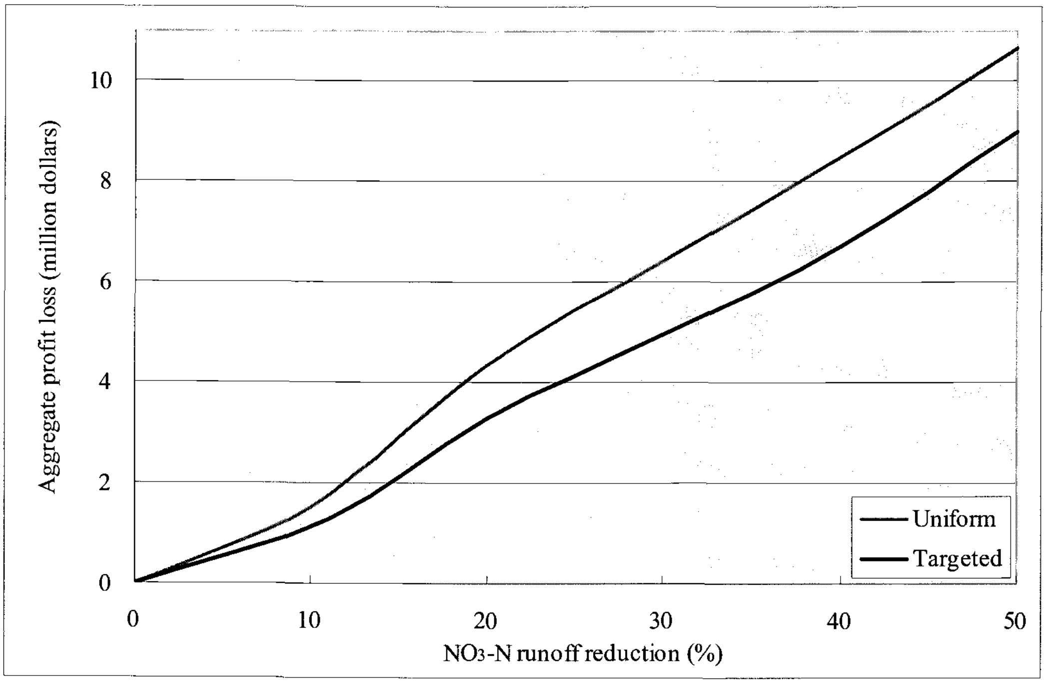

Figure 4.8 Aggregate Farm Profit Loss Under the Targeted and Uniform Taxes in the Des Moines Watershed

CONCLUSIONS

This study evaluates the relative efficiency of targeted (non-uniform) and uniform fertilizer-use taxes for reducing NO_3-N runoff from agriculture. The effect of the fertilizer-use taxes on farm profits and NO_3-N runoff is empirically estimated for the Des Moines Watershed in Iowa. To this end, the integrated modeling framework is developed to estimate the effect of taxes on farmers' land use and NO_3-N runoff. The economic models estimate three agricultural land use decisions (CRP participations, crop choice and rotation, and conservation tillage adoption) at more than 4,900 Natural Resource Inventory sites under the targeted and uniform taxes. The economic models also estimate changes in application of nitrogen fertilizer under taxes. Based on results from the economic models, the physical model estimates the effects of changes in agricultural land and input uses on NO_3-N runoff in the Des Moines Watershed.

There has been a long debate over the relative efficiency of targeted and uniform input-use taxes. Although previous two studies by Claassen and Horan (2001) and Helfand and House (1995) derive opposite conclusions, these studies have some limitations in empirical estimations. The integrated modeling framework developed in this paper enables much reasonable evaluation of the issue. Our results suggest that the targeted fertilizer-use tax is much more efficient than the uniform tax. The efficiency gain under the targeted tax is primarily due to spatial heterogeneity in the Des Moines Watershed. This watershed has a large variations in cropping patterns, soil properties, climatic conditions, and hydrologic characteristics across its subbasins. Overall, this study predicts that the targeted fertilizer-use tax reduce the aggregate farm profit loss under the uniform fertilizer-use tax by up to 30 percent.

The three issues need to be suggested for future research. First, although empirical results suggest that the targeted tax outperforms the uniform tax, the targeted tax may result in potentially high transaction costs (Fort 1991). Because benefits and costs of policies vary across subbasins under the spatially heterogeneous conditions, policymaker needs to obtain much more local information to implement the differential taxes. In addition, under the targeted tax, each farmer's fertilizer application needs to be monitored to prevent a potential resale problem. The relative efficiency gain under the targeted policy may be less than our estimates if these implementation costs are considered. It should also be pointed out that differentiating tax across subregions may be politically difficult or prohibitive to implement. Second, this study assumes that output prices are exogenous, because changes in production in such a small watershed is not likely to affect output prices. However, the fertilizer-use taxes can affect crop prices through changes in crop supplies when the tax is imposed on a large region, which in turn affects farm profits. Third, the resolution of the targeted taxes in this study can be improved. Although this study designed the targeted tax policy by differentiating the tax rates across 9 subbasins, the economic and physical characteristics may different across farmers even in the same subbasin. Thus, a more differentiated targeted policy (e.g. farm-specific tax) may increase the efficiency gain, but it may also increase the cost of implementation.

ENDNOTES

1 Blue-baby syndrome (methemoglobinemia) is caused by exposure to elevated levels of nitrite in infants less than 6 months old. Nitrite adversely affects the blood's ability to carry oxygen, which result in a bluish color in the infants skin. If not treated, this syndrome can be life threatening.

2 Hypoxia (or hypoxic zone) refers to an area in which water near the bottom contain less than 2 parts per million (ppm) of dissolved oxygen. Hypoxia can cause stress on death in bottom dwelling organisms that cannot move out of the hypoxic zone. In the Gulf of Mexico, hypoxia has been identified every year sine early 1970s.

3 The logit probability is derived from the farmer's utility maximization. That is, the probability of choosing crop k in microunit j in subbasin i actually depends on the utilities from producing alternative crops in the microunit. Assuming farmers are risk-neutral, however, maximizing his utility equivalents to maximizing his profit.

Equation (8) is known as the binary logit form, representing the probability in which there are two alternatives. If there are more than two alternatives, the probability takes the multinomial logit form:

$$\text{Prob}_{ij}(k) = \frac{\exp\left(\pi_{ij}^{k}(N_i, \tau_i)\right)}{\sum_{k=1}^{K} \exp\left(\pi_{ij}^{k}(N_i, \tau_i)\right)}$$

4 Under a region where different tax rates are imposed, farmers facing lower tax rates could buy large quantities and resell to those who would otherwise face higher tax rates (Helfand and House 1995).

5 Any tillage operation is referred to as conservation tillage, if at least 30 percent of crop residue is left after harvesting (e.g. no-till). Conventional tillage refers to any tillage operation leaving less than 15 percent of crop residue after harvesting (e-g. chisel-plowing).

6 The CRP, administrated by the Farm Service Agency (FSA), is a voluntary land retirement program for agricultural landowners. The CRP was originally enacted in 1985, and remains the largest agricultural land retirement program in the U.S. Through CRP, agricultural landowners receive annual rental payments and cost-share assistance to establish resource-conserving cover on eligible cropland (Farm Service Agency 2003).

7 In the physical model of this study, 201 Kg ha^{-1} of nitrogen fertilizer is split-applied to corn-soybean rotation and continuous corn. More specifically, 112 Kg ha^{-1} of

anhydrous ammonia is applied as a preplant, and 89 Kg^{-1} as a sidedressing application. Further information is described in table 4.2.

8 The 1-degree DEM is also called as 30-meter DEM. Each cell of this 30 by 30 meter grid is given a single elevation value.

9 Expansion factors in the Natural Resource Inventories are reported in acres. We convert the values to hectares and used for the empirical study.

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CHAPTER 5

GENERAL CONCLUSIONS

Katsuya Tanaka

Although modern U.S. agriculture is noted for its high productivity, it is also identified as a significant source of NPS pollution, mainly due to its chemical intensive management. The most recent national water quality inventory reports that agricultural nutrients, including nitrate-N (NO_3-N) are the third largest pollutant in the surveyed waters (Office of Water 2002). To control and reduce agricultural NPS pollution, numerous government programs are available. For example, the 2002 Farm Bill places a strong emphasis on voluntary conservation on private farmland by establishing and reauthorizing a number of programs. These programs provide incentive payments to farmers who adopt conservation practices on their land (e.g. Conservation Reserve Program, Environmental Quality Incentive Program, and Conservation Security Program). However, there is little evidence that these payment programs are cost effective compared with other commonly suggested policy instruments for controlling NPS pollution such as a chemical input-use tax. This dissertation addresses this question empirically.

The first paper estimates quantitatively the effect of three commonly suggested policies on agricultural land use in the Upper Mississippi River Basin. Site-specific land use decisions are estimated using a set of discrete choice models and data from 1982, 1987, 1992, and 1997 Natural Resource Inventories and other site-specific information. The models are then used to predict farmers' choice of crop, crop rotation, and participation in the Conservation Reserve Program at more than 48,000 NRI sites under: (1) nitrogen fertilizer-use tax; (2) incentive payments for corn-soybean rotation; and (3) Conservation Reserve Program. Results suggest that acreage planted to "polluting" crops (corn and soybean) are quite responsive to the fertilizer-use tax, but not as responsive to the incentive payments for corn-soybean rotation and Conservation Reserve Program.

The second paper develops an integrated modeling framework to evaluate the social cost of alternative conservation policies for reducing NO_3-N concentrations in the Upper Mississippi River. In this framework, the economic models predict farmers' crop rotation, tillage practices, and participation in the Conservation Reserve Program under the four conservation policies at more than 44,000 Natural Resource Inventories sites in the Upper Mississippi River Basin. The estimated land use changes are incorporated into the Soil and Water Assessment Tool to assess NO_3-N concentrations in the Upper Mississippi River. Results suggest that the nitrogen fertilizer-use tax is much more cost effective than the three payment programs. Incentive payments for conservation tillage practices are most cost effective among payment programs, but can only reduce NO_3-N concentrations by a limited amount. The potential of incentive payments for corn-soybean rotation for reducing NO_3-N concentrations is even more limited. They also impose a higher cost to society than payments for conservation tillage. The Conservation Reserve Program can achieve the highest level of NO_3-N concentrations, but imposes the highest cost to society among policies considered in this paper.

The third paper evaluates the relative efficiency of targeted and uniform fertilizer-use taxes for reducing agricultural water pollution. The integrated modeling framework developed in the second paper is refined and improved for enhancing prediction accuracy. The model estimates NO_3-N runoff from the 9 subbasins and associated farm profit loss under targeted and uniform taxes in the Des Moines Watershed in Iowa. In contrast to some previous studies, this study finds that the targeted fertilizer-use tax reduces the aggregate farm profit loss under the uniform fertilizer-use tax by up to 30 percent.

In summary, the first paper examines agricultural land use changes under alternative conservation policies. Although this paper does not have much environmental implications, simulated results provide strong basis for empirical analyses in the following two papers. The second and third papers examine agricultural land use changes and water quality under alternative conservation policies, and their cost effectiveness. Results suggest that the nitrogen fertilizer-use tax is much more cost effective than the three incentive payment programs. In the presence of spatial heterogeneity of land quality and physical characteristics, the targeted (non-uniform) fertilizer-use tax outperforms the uniform tax significantly. These results suggest that although 2002 Farm Bill places a significant emphasis on conservation payments, input-use control through taxes are more efficient economically. Results also suggest that the targeted fertilizer-use tax outperforms the uniform tax under the spatially heterogeneous conditions. These are the major findings and contributions of this dissertation. Another contribution of this dissertation is the integrated modeling framework developed and used in the second and third papers. The framework provides a way of analyzing NPS pollution at the region scale, while taking individual farmers' profit-maximizing decisions into account.

In this dissertation, conservation policies are evaluated based on economic efficiency. However, to determine the optimal water quality target, we must take social benefits as well as social costs into account. To estimate social benefits, we need to measure all benefits to society from improved water quality, including benefit to fishery, biodiversity, freshwater and saltwater recreation activities, and human health. However, measuring all of those effects is difficult and nearly impossible. For this reason, this dissertation estimates the social costs of achieving alternative water quality targets under alternative conservation policies.

In the third paper, empirical results suggest that the targeted fertilizer-use tax outperforms the uniform tax under the spatial heterogeneous watershed. The targeted tax, however, may result in potentially high transaction costs (Fort 1991). Because benefits and costs of policies vary across subbasins under the spatially heterogeneous conditions, policymaker needs to obtain much more local information to implement the differential taxes. In addition, under the targeted tax, each farmer's fertilizer application needs to be monitored to prevent a potential resale problem. The relative efficiency gain under the targeted policy may be less than our estimates if these implementation costs are considered. Finally, it should be pointed out that differentiating tax across subregions may be politically difficult or prohibitive to implement.

This study can be extended in several aspects in the future research. First, the integrated modeling framework can be applied to other topics related to agriculture and water quality problems. For example, the framework can be extended to analyze the effect of conservation policies on groundwater quality. Second, although this study evaluates the relative efficiency of targeted and uniform input-use tax, it does not evaluate the relative efficiency of targeted and uniform incentive payments. Estimating the efficiency gains from a targeted payment program is another interesting topic for future research.

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