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AN EXPLORATION OF THE ECONOMICS OF FARM MANAGEMENT ALTERNATIVES TO IMPROVE WATER QUALITY

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ABSTRACT

A tool has been developed which allows the graphical exploration of the tradeoff between farm income and concentrations of pollutants leaving a field. A comprehensive simulation model is used to develop the technical relationships relating farm income to pollutant concentrations given different management practices. Mathematical programming is used to select the most profitable management practice under assumed constraints on the concentrations of different pollutants which can be emitted. The most profitable management practices associated with different concentrations of pollution entering surface and groundwater are displayed graphically. A field near Treynor, Iowa has been analyzed as an example.

KEYWORDS: water quality, economics, graphics

Introduction

One of the inherent difficulties in reducing agricultural nonpoint source water pollution from agriculture is the lack of information relating the effect of agricultural practices on water pollution. The stochastic nature of climatic factors interacts with farm production practices and site specific physical features such as soil characteristics and watershed geometry to determine the loading of sediment, fertilizers and pesticides into surface and groundwater. Monitoring the concentrations of agrichemicals from all agricultural land would be extremely expensive, yet society cannot afford to ignore the potential threat to water supplies from nonpoint sources. Information technology has a key role to play in reducing nonpoint source water quality problems by informing decision makers about the consequences of land management practices. As part of the USDA's Water Quality Initiative, the Agricultural Research Service is currently developing a prototype decision support system (PDSS) which uses a simulation model within a multiobjective framework in order to select the best alternative management practice (Yakowitz et al, 1992).

As a complement to the PDSS, a more detailed economic analysis of the incentives facing a farmer has been developed. In selecting an improved management practice for a given field one would like to achieve the social objectives of producing food or fiber without damaging the usefulness of water bodies receiving water from the field. In general the farmer does not bear all of the costs of the pollutant loadings, therefore he may neglect the pollution's cost to society

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when selecting land management practices. This paper presents an application of information technology which allows the user to explore the effects of different management practices on farm income and pollutant concentrations in order to help select management practices which meet the farmer's need for income and society's need for clean water.

The most likely users of the PDSS are conservation specialists rather than professional economists. Hence, the goal is to provide a series of graphs which define the scope of the water quality problem and give an intuitive understanding of the economic incentives facing a particular farmer without requiring detailed analysis from the user. Graphics are increasingly being used in production economics (Debertin et al., 1991), but they have not been applied to full advantage in decision support systems for natural resource management.

There are two primary goals in economic analysis, equity and efficiency. Equity considerations focus on identifying winners and losers and quantifying how much is won and lost. In this paper, no attempt is made to analyze equity implications other than the farmer's gain or loss from adopting alternative land management practices. An outcome is said to be economically efficient if it maximizes the net benefits (without considering to whom the benefits and costs accrue). An idealized graph of the marginal benefits and costs of controlling pollution can be seen in Fig. 1. As the environment can generally assimilate some amount of pollution, at low levels pollution the marginal benefits (MB) of performing a polluting activity outweigh the marginal environmental costs (MC). It is possible to increase the amount of pollution up to an efficient level where the marginal benefits equal marginal costs and net benefits, so that the net benefits, or the area below MB but above MC, is maximized. A more frequent case, however, is when the marginal costs are greater than the marginal benefits and net benefits can be increased by reducing the amount of pollution emitted. If the marginal benefit and marginal cost curves could be calculated for a given pollutant, then a policy could be developed to maximize net benefits.

As a practical matter, information requirements preclude any attempt to calculate the efficient pollution level. Instead, standards are typically used. In the words of Baumol and Oates (1988: p. 160), *"The use of predetermined standards as an instrument of environmental policy recommends itself primarily because of the vast information required by the alternative approaches"*. Indeed, for nonpoint source water pollution the information required for improved management is substantial, especially for the off-farm costs of deteriorating water quality. By using standards and applying information technology those practices which maximize the farmer's income while meeting water quality standards can be identified for promotion.

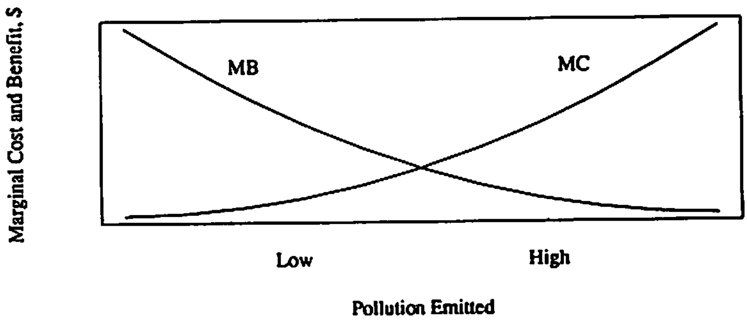
Idealized Graph of Optimal Pollution Loading

Figure 1

Controlling nonpoint source water quality problems from a given field requires determining if there is a water quality problem and if alternative management practices can reduce the concentrations of those pollutants. Also, are there economic incentives to adopt those alternative practices? If these questions can be answered, a conservation agency can concentrate its efforts on problem areas and develop more effective programs based on the incentives facing the farmer. If the economic incentives facing farmers do not lead to the adoption of acceptable conservation practices for water quality, then it may be necessary to examine the possibility of changing those incentives. Swanson (1982) discusses a number of policies designed to change the incentives facing farmers to apply nitrogen fertilizer.

Method

There are three steps in the analysis of a given field. First, a simulation model is used to estimate income and pollutant concentrations from alternative management practices. Second, a mathematical programming model is used to select the management practice which earns the farmer the most money given different constraints on the concentrations of pollutants coming off the field. Third, a series of graphs present the user with information from the two models in a way which demonstrates the cost to the farmer of controlling nonpoint source water pollution.

As no single simulation model provided all of the variables needed for water quality decisions with the PDSS, parts of several models were integrated to form a comprehensive simulation model, capable of simulating the movement of sediment, nutrients and chemicals to the edge of the field and leached below the root zone. The GLEAMS field scale simulation model (Davis et al, 1990) provides the hydrology, erosion and pesticide components, to which have been added the nutrient component from CREAMS (Knisel et al., 1980) and the crop growth component of EPIC (Williams et al., 1989), including the ability to model nitrogen fixation by legumes. In addition, the economic program CARE (Midwestern Agricultural Associates, 1988) has been modified to use the simulated crop yield to estimate the returns to land and management from the field, hereafter termed "net income". Further, an interface has been built which allows one to easily set the parameters of the simulation model for a given field (Hernandez et al., 1993).

A mathematical programming model in the GAMS language** (Brooke et al, 1988) has been built to study the tradeoff between water quality and farm income. The math programming model is a constrained optimization approach which maximizes farm income per hectare subject to a set of constraints which limit the solution to those practices which are technically feasible. An additional set of constraints limit the emission of pollutants to an acceptable level. The difference between the maximum net income which is technically feasible and that which is both technically feasible and meets the emission standard is the cost to the farmer of meeting the standard. A mixed integer solution algorithm is used to force the whole field to receive the same management practice. An assumption of this formulation is that the farmer is profit maximizing, although with a nonlinear solution algorithm it is possible to consider risk aversion as well. One of the drawbacks of this approach is that only average annual concentrations of the pollutants are considered, not peak concentrations. Nor does the approach imply when or even whether farmers would adopt a different management alternative; it simply indicates whether or not a farmer has an incentive to adopt a certain management practice.

**GAMS is a trademark of the Scientific Press and S-PLUS is a trademark of Statistical Sciences, Inc. The mention of these products does not imply their endorsement by the USDA-ARS.

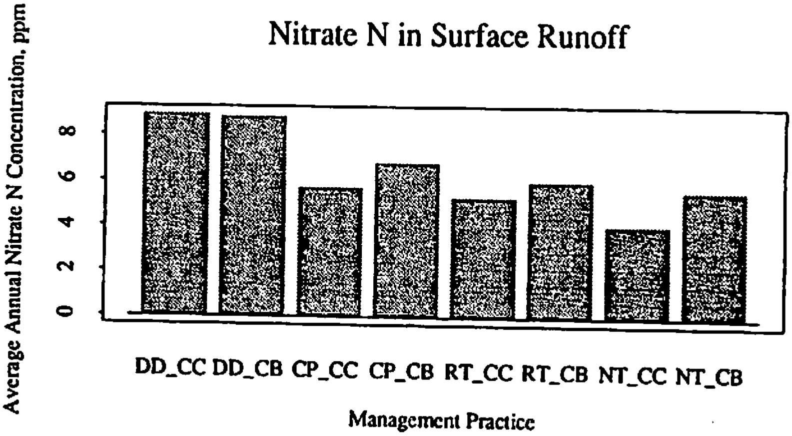

Figure 2

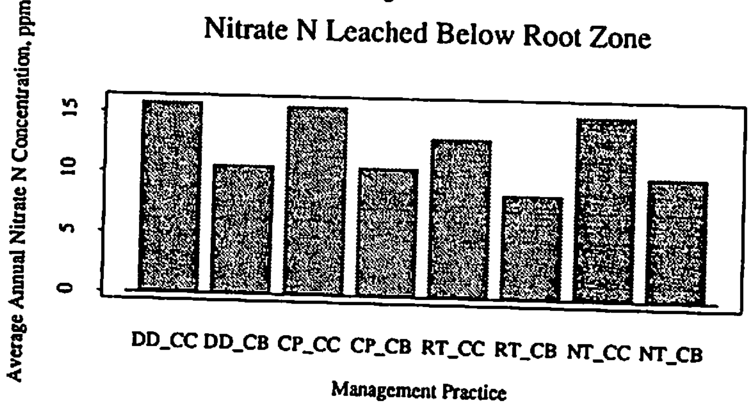

Figure 3

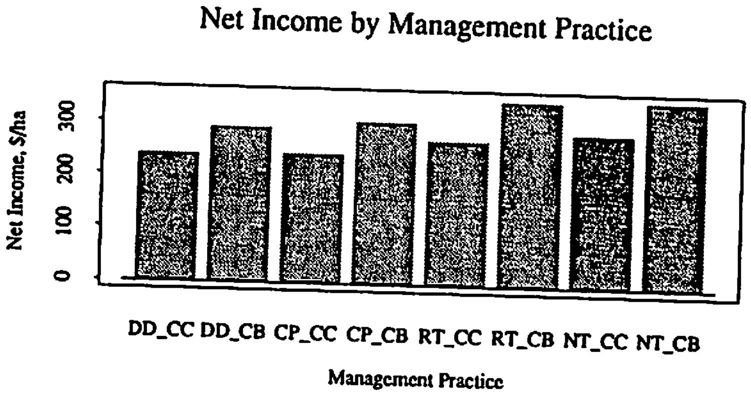

Figure 4

water on the field leached greater quantities of nitrate nitrogen, the nitrate nitrogen was diluted by greater amounts of water percolated below the root zone. The fate of the nitrate is unknown after it moves below the root zone and the link between surface and groundwater is unknown. In reality, some of the water leaving the root zone reappears as baseflow, so nitrate leaving the root zone ultimately affects surface water as well as groundwater. The simulated average nitrate nitrogen concentration for deep disking with continuous corn is roughly 15 ppm, indicating that there could be a problem with leached nitrate, which is confirmed by measurements of nitrate concentrations in groundwater taken at Watershed 1 and the similarly farmed, adjacent Watershed 2 (Deep Loess Research Station, personal communication).

The most basic economic variable is the average annual net income per hectare for each management practice, shown in Fig. 4. The corn soybean rotation earns more than the continuous corn rotation for each tillage practice. Also, the tillage practices which hold more water on the field, appearing farther to the right, tend to earn a higher average net income, both because yields are higher due to lower water stress and because costs are lower with fewer tillage operations. If the problem were to select the management practice which earns the highest returns without consideration of nitrate nitrogen concentrations, either the no till or ridge till with the corn and soybean rotation would be selected, as they earn the most, $352 and $348 per hectare respectively.

If nitrate nitrogen concentrations in water leaving the field were a problem, would the same profit maximizing management practice be selected? Figure 5 is a scatterplot relating net income to nitrate nitrogen concentrations in surface runoff for the eight management practices. The current practice on the study watershed, deep disking with continuous corn, is represented by the solid square. Although there is not a problem with nitrate in runoff, all other management practices do better than the current practice, either by earning more or producing less nitrate nitrogen in the runoff, or both.

Figure 6 is similar to Fig. 5, but it shows how the results of the simulation model are used by the math programming model to select the management practice with the highest net income given constraints on the concentration of nitrogen in the runoff. The first point to notice is that the x axis has changed and is no longer average annual nitrate nitrogen concentrations, but *the constraint on* nitrate nitrogen concentrations. The points representing management practices are not as dispersed horizontally as in Fig. 5, because the practices are graphed by the constraining level of nitrogen in runoff which that practice satisfies (the concentration has been rounded up to the nearest ppm). The line on Fig 6 indicates the most that could be earned at any standard level by selecting from among the technically feasible practices considered that most profitable practice for which the average annual nitrate nitrogen concentration does not exceed the value on the x axis. Essentially, the math programming model mimics a profit maximizing farmer who selects a management practice given information on the net income of each practice and the allowable concentration of nitrogen in the runoff.

If the farmer were constrained to produce between 0 and 4 ppm nitrate nitrogen in runoff there would be no income, because none of the management practices considered produce concentrations less than 4 ppm. It should be noted that there is typically a background concentration of nitrogen, so that a standard of 0 ppm is unrealistic. If the constraint were relaxed to 5 ppm, a single management practice, no till with a continuous corn rotation, is feasible and earns $289 per hectare (see Figs. 2 and 4). The no till with a corn soybean rotation practice earns more, $352 per hectare, and produces concentrations averaging less than 6 ppm, as does ridge till with a corn soybean rotation earning $348. Even if the allowable concentration were relaxed to 20 ppm, there are no practices tested which earn more than no till with a corn soybean rotation, so a profit maximizing farmer would not select a different practice even if he were allowed to produce higher concentrations of nitrogen in runoff.

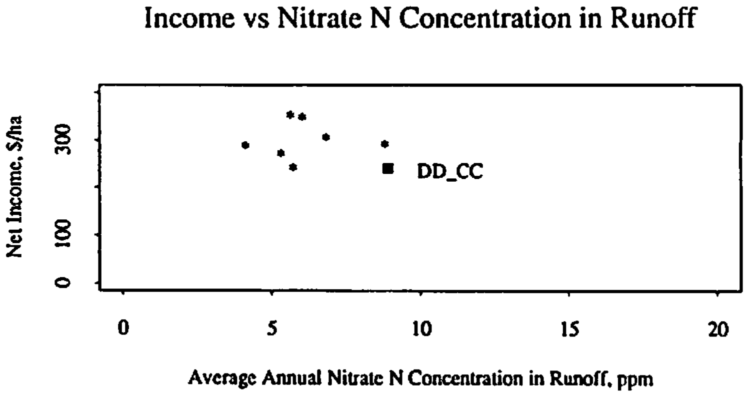

Figure 5

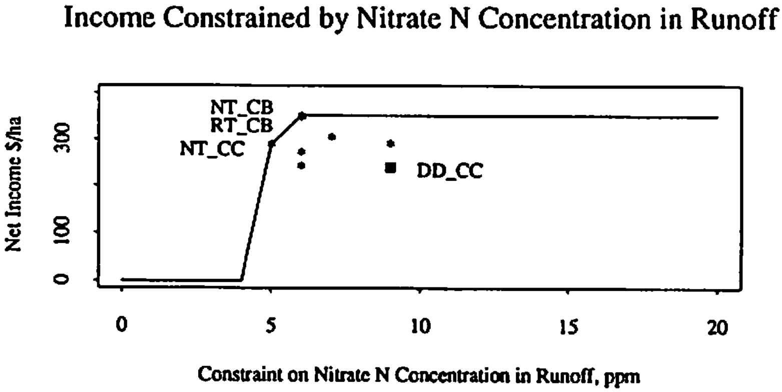

Figure 6

In order to see the whole economic - water quality tradeoff at a glance, Fig. 6 has been modified by the inclusion of a third axis, a constraint on nitrate nitrogen leached to produce Fig. 7. The 3 points representing the management practices with the highest incomes given the constraints on nitrate nitrogen leaving the field are marked at the corners. A flat surface extending away from a corner indicates that no other management practice would earn more money for the farmer and still meet the constraints given on the x and y axes. Thus, by choosing from among the indicated points in Fig. 7, one can select the concentration of nitrate nitrogen leaving the field as runoff or leachate, knowing that income is as high as possible for those concentrations.

Simulated earnings and nitrate concentrations are so similar for ridge till and no till that given the uncertainties in the simulation model and its parameters, the two practices should be considered equally desirable, both economically for the farmer and in terms of nitrate concentrations. Before concluding definitively that either ridge till or no till with a corn soybean rotation should be promoted, one would want to see graphs of other pollutants, such as sediment and herbicides, which could be problems with reduced tillage practices.

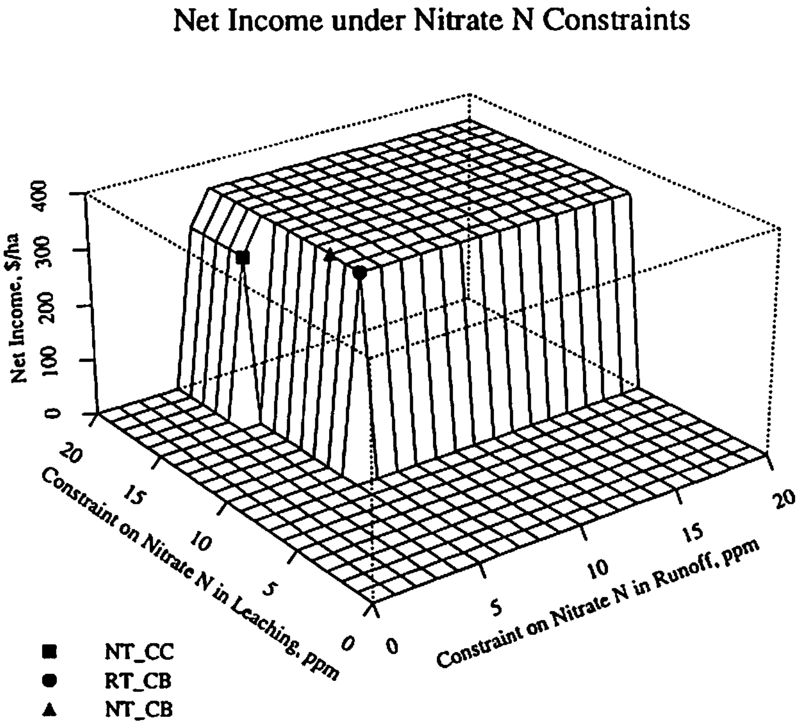

Figure 7

From Fig. 7 it appears that even with conservative assumptions about the fate of nitrate after leaving the field, two management practices (no till and ridge till with a corn soybean rotation) exist which provide acceptable levels of nitrate nitrogen concentrations leaving the field and, happily, earn the farmer the most money of the practices considered. If one is still unsure that the concentration of nitrate leaving the root zone is safe, it is possible to explore variations on the best management practices such as lower fertilizer application rates or changes in timing.

Figure 8 shows a revised graph similar to Fig 7, except that a ninth management practice, ridge till with a corn soybean rotation but with no nitrogen applied to the corn has been included. The "step" on the right hand side showing net income of $253 per hectare at less than 7 ppm nitrate nitrogen leached represents the limit to which nitrate nitrogen leaching can be controlled. Although it is encouraging that income does not decrease much (the soybean crop is not affected), it is discouraging that there is such a small decrease in nitrate leached beyond the level achieved by the ridge till corn soybean rotation with 140 kilograms of nitrogen applied management practice. The amount of control over the nitrate concentration in leachate is limited by the fact that most of the soil on the watershed is a mollisol. With a high organic content, mollisols can mineralize organic nitrogen to form nitrate even if little nitrogen fertilizer is applied, at least over the short planning period considered here.

The simulation model can also be used to explore the results of varying the amount of fertilizer applied. Figure 9 for example, shows an estimate of the effect on net income of varying nitrogen applications from 0 to 200 kilograms per hectare for the corn crop in the ridge till corn soybean

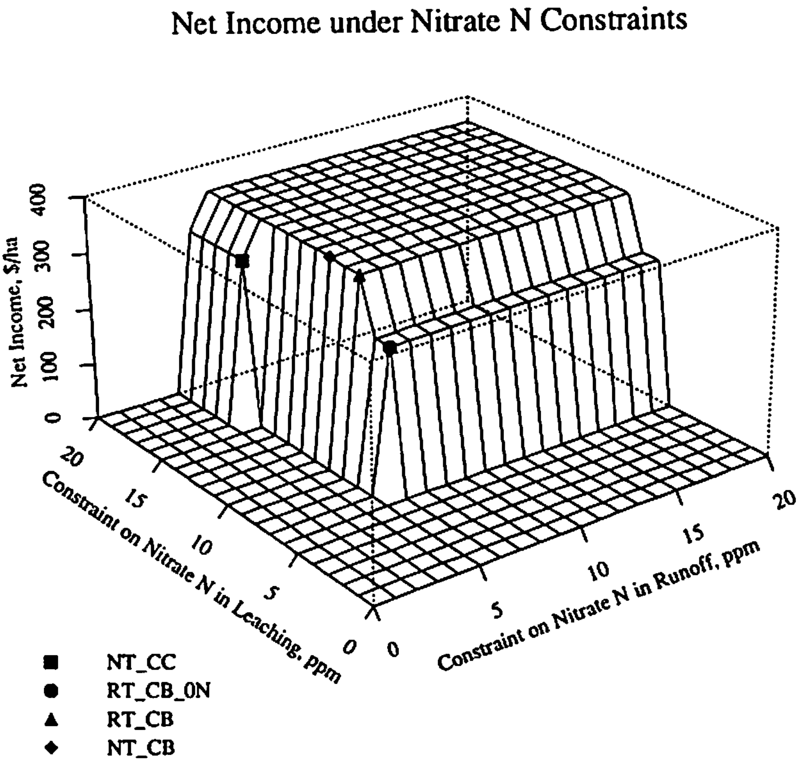
Net Income under Nitrate N Constraints

Figure 8

practice. There is a net income plateau beginning at roughly 80 kilograms of nitrogen per hectare where significant yield losses due to nitrogen stress stops. Fertilizer application rates should be made on the basis of soil tests rather than the simulation model used here. Nevertheless, the net income plateau indicates that nitrogen applications can probably be reduced significantly from

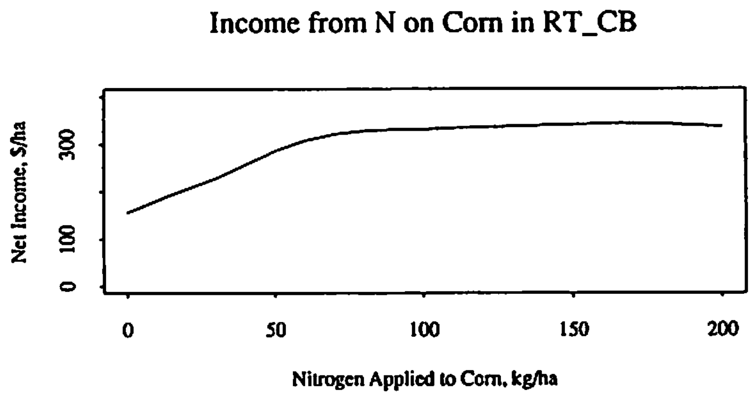
Income from N on Corn in RT_CB

Figure 9

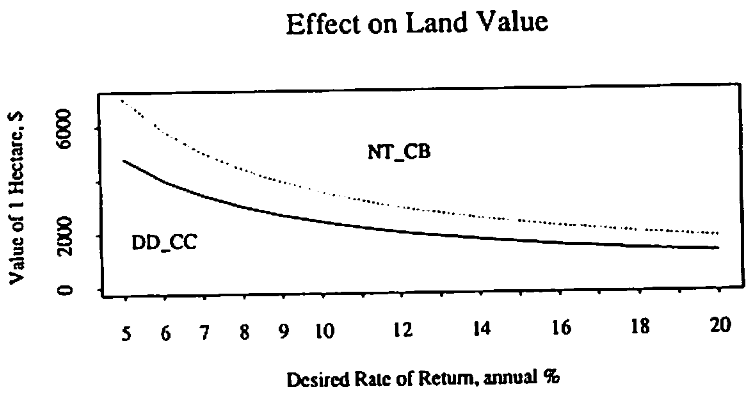

Figure 10

current rates without reducing the farmer's net income much. On the other hand, application of fertilizer beyond the optimal point as "yield insurance" is not very costly to the farmer, even though it may lead to excessive concentrations of nitrate nitrogen leaving the field.

One final economic consideration is the value of the farm land. If management practices are changed to protect water quality and the change reflects a permanent change in the income stream from the field, then the change is capitalized into the price of the land (assuming the new owner will use the same practice). The change in the value of the land is only an issue to a farmer thinking of selling the land; if the farmer intends to farm the land indefinitely, then only the change in the income stream is relevant. The value of land can be estimated by dividing the net income by the rate of return one would expect for an equally risky investment. Figure 10 shows the value of one hectare on Watershed 1 given different required rates of return for a potential buyer. The bottom curve is the current practice, deep disking with continuous corn and the top curve represents no till with a corn soybean rotation. In this case, the adoption an alternative management practice would increase income, increasing the value of the land. Of course, if the income declined from adopting a new management practice the value of the land would decline accordingly. This information would be of particular interest to farmers nearing retirement age.

Future Improvements

A number of improvements to the simulation model used in the PDSS are under consideration which would strengthen the ability to analyze the economics of nonpoint source water quality problems. One improvement would be to include an analysis of extreme events which are very important for water quality, particularly pesticides. A second improvement would be the development of confidence limits around the simulated pollutant concentrations. A third possible improvement is to include other simulation models allowing more detailed simulation of the movement of pollutants, or link to other models in order to estimate the effect of pollutant concentrations on the streams, lakes and aquifers which receive water from the field.

The economic analysis could be strengthened by considering discounted income streams if some of the management practices involve large capital investments, for example, terraces. The ability to select management practices for a number of fields at the same time, as a whole farm, would more accurately reflect many of the technical constraints in farm management practice selection, as well as aiding in the consideration of risk aversion. In addition, more economic information for improving water quality could be provided by the mathematical programming model in addition to that shown. A study of the sensitivity of the outcomes to price changes is possible, as are more detailed analyses of the incentives facing farmers. For example, one could study the effect of time constraints on the incentive for farmers to purchase custom applications of herbicides rather than spending time on mechanical cultivation during the busy spring period. More detailed market information can also be developed such derived demand curves for inputs and of output supply curves as described in Paris (1991).

Summary and Implications

This paper has presented an application of information technology which allows a conservationist to easily determine if there is a problem with a given pollutant leaving a field. At the same time, the conservationist can also see which practices a farmer could adopt and at what cost in income from the current practice to meet a standard for surface or groundwater. If the cost to the farmer of adopting an alternative practice is small those practices can be promoted. On the other hand, if the cost is large, perhaps some way to reduce the cost will be necessary before the farmer adopts the alternative practice. In some situations, such as the example analyzed, it may be possible to see that an improvement in both farm income and water quality is possible.

Before any simulation model can be used routinely to analyze the economics of water quality problems, a tremendous amount of data must be collected and made available about the physical characteristics of the fields and the economics of the different practices. It is important to emphasize the need for good data as input to the simulation model. Without the proper parameters the use of a simulation model is a potential case of information technology making misleading information more accessible. When possible, simulation results should be compared to observable farmer behavior. For example, if one went through the example of Watershed 1 at Treynor, Iowa and there had not been a shift toward tillage practices which reduced runoff and toward a corn soybean rotation on similar fields in the area, one should check to see if the farmers know something which has not been included in the parameters of the simulation model or in the model itself. If some farmers have freely adopted either ridge till or no till with corn soybean rotations, then an educational program designed to encourage further adoption would be appropriate. Such an educational program would be especially effective following periods of low rainfall, when the effect of holding more water on the field to reduce water stress is apparent.

Economic incentives are important determinants of farmer behavior. If large numbers of farmers in a given region must adopt conservation practices in order to control water quality problems, then attempts should be made to insure that the incentives facing farmers do indeed lead to the adoption of conservation technology. If there are conservation practices which would earn the farmers money, then those practices should be encouraged. On the other hand, if farmers have already adopted all of the conservation practices which provide higher returns and standards still are not being met, then conservationists should think about modifying the incentives facing farmers. Information technology has a role to play in reducing the cost of site specific economic and technical information so that better conservation decisions can be made. If enough data are available, a simulation model linked to a mathematical programming model with graphics can be used to explore the incentives facing farmers, leading to more informed and consistent natural resource decision making.

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