Cost-Share Incentives and Best Management Practices in a Pilot Water Quality Program

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This study integrates three biophysical simulators to predict crop yields, water-soil pollution emissions, and farmers' net returns under uncertain weather and market conditions. Multiple-objective programming incorporates farmer attitudes toward voluntary participation under alternate rates of government cost-share subsidies to search for efficient pollution abatement solutions as best management practices (BMPs). Net returns decline an estimated 9.6% when farmers adopt a cost-share program with a $2.50/acre subsidy, while reducing N leaching by 2.7%. For a $10/acre subsidy, N leaching can be reduced by almost 6%, but farmer net returns decline by 15%.

Key words: best management practices, biophysical simulation, cost-share incentives, multi-objective programming, nonpoint pollution, water quality

Introduction

Agricultural production and management practices generate soil and water externalities which are inherently nonpoint sources of pollution, and thus extremely difficult and expensive to quantify through measurement or monitoring. Traditionally, land and water pollution generated by production technology have been either undetectable or ignored. Without measurement and monitoring, implementation of efficient management or abatement practices is difficult or impossible. In his 1952 analysis, Meade postulated that externality levels may be dependent on the amount of productive factors employed. Griffin and Bromley extended previous work to develop economic guidance for nonpoint pollution policy, suggesting the reliance upon nonpoint pollution functions which estimate the pollution based on production activities.

Linking nonpoint agricultural pollution of groundwater to actual management policies and economic impacts requires substantial information (Anderson, Opaluch, and Sullivan). The site-specific nature of nonpoint pollution events suggests that such information be available at the farm and regional levels (Stevens). The development of emissions-yielding simulation models creates an opportunity to establish the relationship between crop management practices and their potential for pollution externalities. Several biophysical simulators have dramatically raised the speed and accuracy of

simulated information and have become generally accepted by agricultural/resource economists in their policy analysis (e.g., Johnson, Adams, and Perry; Zhu, Taylor, and Sarin; Kim and Mapp; Mapp et al.).

This study evaluates farmers' optimal management practices when government incentive schemes may be applied individually to each factor on which externality generation depends. We examine crop production and nonpoint pollution emission with risk and uncertainty explicitly considered, and discuss abatement implications in the case of voluntary adoption of altered management practices. We integrate crop growth and nonpoint pollution simulators with farmers' preferences for participation in a cost-share program to establish expectations of farmers' net returns and representative emission levels. Efficient management practices for an example case in the Gum Creek Watershed of southern Georgia are obtained by multiple-objective programming analysis. Sensitivity to altering rates of government cost shares is considered.

In the following section, the economic considerations for voluntary participation in an abatement program are examined. Next, the empirical framework employed in the analysis is outlined. The case of voluntary adoption of integrated crop management in the Gum Creek Watershed is then presented, with subsequent conclusions and implications based on the performance of the analytical framework and the individual case study.

Economic Considerations

Griffin and Bromley began their economic modeling process with the point-source externality case of Baumol and Oates, and extended it to the nonpoint case which is more common in agricultural production. We begin by assuming, as did they, that it is difficult or impossible for the government to find the appropriate levels of incentives (subsidies or penalties), σ^*, which would control agricultural nonpoint source pollution at the desired levels—Z for each farm, or Z^* for all farms in the concerned area. If the payments are less than σ^*, farmers would engage in production activities at levels which fail to achieve the desired (or acceptable) emission levels. If the payments are more than σ^*, farmers would control the emissions at levels which are excessive to the desired levels or standards, Z^*. In this case, the payments would not be efficient. Moreover, an iterative, trial-and-error procedure to discover the optimal payments is a long-term concept, whereby implementation and/or adjustments of the payments are usually made after some potentially serious negative effects of the emissions have been detected.

Whether using incentives (subsidies/penalties) or regulations, monitoring is required for emissions. While monitoring point-source emissions is costly, monitoring nonpoint source pollutants is either infeasible or impractical (Griffin and Bromley, p. 548). If production activities generate nonpoint pollution, however, and if the results of those activities on the emissions levels can be quantitatively defined, then incentives can be offered to subsidize/penalize the producing unit to reduce those activities. The difficulty and expense in obtaining this information can be reduced if current nonpoint pollution simulators could be used to predict runoff and emission levels accurately, thus resolving the missing data/measurement cost problems associated with the nonpoint source polluting activities (Moxey and White, p. 33).

Under certainty and without a government subsidy, firms equate marginal revenue from their activities to the marginal cost of those activities to select their optimal

activity levels. If, however, the government (public) were to offer a lump-sum subsidy, potential participants would then equate their marginal total revenue, including the subsidy, to marginal costs, which would have the effect of reducing their pollution-related activities to match the pollution targets $\mathbf{Z}^*$. Thus, the effective price received per unit produced rises when obtaining a subsidy σ^j, and marginal costs would be expected to decline if the subsidy was to compensate for reduced usage of certain inputs. Producers would control the emissions levels at $\mathbf{Z}$ when they are paid (penalized) by the government with subsidies (penalties) at σ^*. The government then must choose its subsidy policy to encourage sufficient participation to maintain a tolerable (acceptable) pollution level and retain productive, profitable agriculture.[1]

Efficient Cost-Sharing Under Uncertainty

To determine the effectiveness and impacts of a voluntary abatement program in agricultural production activities, the rate of adoption of management alternatives also must be resolved. Just what are the farmer's incentives to reduce production returns on a "cost-share" (or some other) basis? Perceptions of risks and uncertainty related to yields and income levels influence producers' decisions to voluntarily adopt a management system (Christensen and Norris). Spofford, Krupnick, and Wood identify several sources of uncertainty in groundwater quality management. Uncertainty with regard to the physical process occurs as various factors, such as timing and magnitudes of natural hazards, rates of chemical use, and geologic and hydrologic heterogeneity, influence the application of chemicals on the soil and their transportation under the ground. For example, random occurrence of rainfall could transport chemicals applied to surface water and/or to groundwater, or it could allow the chemicals to remain in the crop root zone, depending on the intensity and timing of the rain.

Farmer behavior often indicates an aversion to risk when faced with a risky situation (Patrick et al.). This risk aversion can be measured as a risk premium, which is defined as the amount of expected wealth (net return) required to make farmers indifferent between the risky outcome and a certain outcome. The amount of risk premium is determined by the individual's risk attitude. Because individual risk attitudes are not directly observed, the risk premium is a random factor in returns. Therefore, the profit-maximization condition should add a term representing the marginal risk premium (MRP) of the (potential or actual) participant.

Considering Ramaswami's discussion of risk and input decisions, the risk-averse individual j's management problem becomes a maximization of expected net returns (total, again including some level of public subsidy/tax) less j's own risk premium (RP) when facing decisions of alternate activity levels, particularly a new management practice. Ramaswami has shown that a risk-increasing input has a positive RP. Because the expected marginal cost (MC) then shifts the MC curve to the left and the marginal total return stays constant, risk-averse individuals would make decisions which tend to reduce their net profits.

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[1] Baumol and Oates, in discussing point-source pollution, suggested that taxes and subsidies were not equally efficient as pollution abatement policies except when they were capitalized into site rents—in effect, lump-sum transfers (p. 231). This was supported in analysis by Wu and Babcock. Chowdhury and Lacewell empirically found symmetric tax and subsidy results for risk-neutral farmers, but supported the Baumol and Oates asymmetric income effect on after-tax and post-subsidy profits for risk-averse farmers.

An efficient externality control program must provide farmers with risk and uncertainty information to induce informed decisions. Close examination of farmers' risk attitudes can assist efficient allocation of the government budget to approach pollution abatement targets. In a cost-sharing water quality program, the individual's risk premium can be considered as his/her abatement cost share, and the government's subsidy can be considered as its (the public's) cost share of the uncertain outcomes of the production decisions. A well-developed cost-sharing program adjusts both shares to the margin so that pollution-related activities are reduced to allowable levels under a risky and uncertain production environment.

Voluntary Cost-Share Adoption

In a voluntarily adopted cost-share program,[2] attitudes toward adoption of the new practices will be determined by producers' expected net returns and pollution levels, as well as by the expected government expenditures. Let p be a farmer's probability of adopting the new management practice when the government shares k percent of the cost of the management activity alternative contracted under the program. The cost of adopting the practice is the reduction of net returns by adopting the new alternative, ΔR (i.e., the net return from the current management practice, R_0, less that from a new management practice, R_1). Let $S_0, S_1, F_0, F_1, L_0,$ and L_1 refer to the soil losses, nitrogen runoff, and nitrogen leaching from both current (subscript 0) and new (subscript 1) management practices, respectively. The expectations of the representative unit's expected net returns (*ENR*), soil losses (*ESL*), nitrogen losses in runoff (*ENF*), and nitrogen losses in leachate (*ENL*) will then be summations of outcomes of both the adoption and the nonadoption possibilities.

For example, suppose an individual's probability of retaining the current management practice is $(1 - p)$ with net return R_0, and the probability of adopting a new management practice is p $(0 \leq p \leq 1)$ with net return R_1 plus the government cost-sharing payment (ΔRk). If a linear combination of voluntary participants and non-participants form the watershed area's response function, the summation of both possibilities, $(1 - p)R_0 + p(R_1 + \Delta Rk)$, would then be the area unit's representative *ENR*. The expected pollution levels would likewise sum outcomes of each alternative multiplied by its probability. The government's expected lump-sum costs (*EGC*) will also depend on the individuals' attitudes toward contractual participation in the program. These representative expectations can be summarized as follows:

(1) $$ENR = (1 - p)R_0 + p(R_1 + \Delta Rk),$$

(2) $$ESL = (1 - p)S_0 + pS_1,$$

(3) $$ENF = (1 - p)F_0 + pF_1,$$

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[2] Cost-share incentives for soil and water conservation in the U.S. began with the Agricultural Conservation Program in 1936. Federal soil and water conservation programs, with their voluntary nature, have relied heavily on cost-share incentives to encourage farmer participation. Walker, Noble, and Magleby indicate that cost-share incentives can serve two purposes for a water quality project: (*a*) compensation to farmers for expenses incurred in generating water quality benefits that accrue to other water users, and (*b*) encouragement of more rapid adoption, trial implementation, and/or maintenance of water quality practice.

(4) $ENL = (1 - p)L_0 + pL_1,$

and

(5) $EGC = \Delta Rpk.$

Willingness-to-accept payment characteristics might be linked to current management, demographics, and other characteristics of individual producers in the region under consideration, and thus the proportion of adopters/nonparticipants in such a voluntary program. An application of this program to a pilot watershed study is presented in the following section.

Gum Creek Watershed Case Study

Gum Creek Watershed (GCW) comprises approximately 53,000 acres in the Coastal Plain of Georgia. Gentle relief, warm and humid weather, and fertile soil enhance intensive agricultural production of a wide diversity of crops. Peanuts, cotton, pecans, pasture, melons, and corn are major crop activities in the watershed. Several subwatersheds have more than 50% of their surface area commonly planted to crops that have high fertilizer and pesticide requirements. Soils with high or intermediate pesticide and nutrient leaching pollution potential cover most upland areas of the watershed. Gum Creek was identified in the state "Nonpoint Assessment Report" and the "Nonpoint Source Management Plan" as an agricultural stream likely to be threatened by agricultural nonpoint source pollution, and Lake Blackshear, which receives the water of Gum Creek, was classified as eutrophic (Georgia Cooperative Extension Service 1992b).

The GCW was selected to be one of 16 water quality demonstration projects nationwide for examining potentially polluting agricultural practices. The GCW project proposes to reduce potential nonpoint source pollution by inducing farmers to voluntarily adopt "best management practices" (BMPs) within a federal cost-sharing pilot program. This case analyzes nitrogen application management and cost-share rate alternatives through the use of biophysical simulation and multiple-objective programming to search for economically optimal BMPs.

Analytical Framework

Integrated crop management, which includes the reduction of nutrient usage in crop production (Georgia Soil and Water Conservation Commission), exemplifies the major BMP contracted in the economic evaluation of the GCW water quality program. Using results of individual farmer surveys in the GCW, we model a representative farm type in the watershed to provide the database for economic evaluations of cost-sharing incentives to alter rates of nitrogen fertilizer application. The integrating approach for this analysis links (a) peanut and corn crop biophysical simulation models to predict crop yields under alternate nitrogen management practices, (b) a soil/water movement simulation model to predict pollution emissions, (c) estimation of the expectations of farmers' net returns and pollution levels associated with alternative management

parameters, and (*d*) multiple-objective programming analyses to assess nitrogen management measures under risk and uncertainty for an area-representative, profit-maximizing production unit. Figure 1 illustrates the analytical framework of the GCW economic study, which is briefly outlined below.

Three locally validated biophysical simulators are assembled to obtain both crop yields and pollution output. PNUTGRO version 1.02 (Boote et al.), a process-oriented peanut crop growth model, simulates and predicts peanut crop development, water and nitrogen balance, and the final peanut yield. CERES-Maize version 2.10 (Ritchie et al.) simulates the growth and yield of corn, produced in rotation with peanuts. GLEAMS version 2.0 (Knisel, Davis, and Leonard) simulates agricultural management systems relating the movement of agricultural chemicals within and through the plant root zone and predicts the resultant water pollution and soil erosion output levels, given crop growth parameters and physical data. Crop yields are simulated with local weather data series, and then farmers' net returns are calculated with corresponding market price data and costs of production.

The simulated net returns and pollution levels with regard to nitrogen (N) application alternatives combine farmers' attitudes toward participation at various cost-share rates (Gum Creek Watershed survey responses) to generate randomized expectations of net returns and pollution levels. A set of regression models estimates the expected values of the parameters for the decision analysis based on outcomes of simulations of the management alternatives for participating and nonparticipating producers.

Because it aims to minimize water-soil pollution as well as to maintain productivity in the agricultural sector, the GCW project is characterized as a multiple-criteria decision-making problem. Multiple-objective programming (MOP) techniques, tackling the problem of simultaneous optimization of several objective functions subject to a set of constraints, can be used to find optimal solutions to such problems. An optimal solution from the multiple-criteria programming must be a feasible solution such that there is no other feasible solution available that can achieve the same or better performance for any one of the objectives without decreasing at least one of the other objectives.

However, the optimization of a vector of objectives generates a set of efficient solutions instead of a single optimal solution. The entire set of efficient solutions should be presented to a rational decision maker, and he or she then selects the one believed most attractive. That is, the decision maker, by reviewing the list of nondominated criterion vectors associated with the efficient extreme points, identifies his or her efficient extreme point of greatest utility (Steuer 1986). A number of MOP applications can be found for agricultural planning and resource management (e.g., Romero and Rehman; Berbel, Gallego, and Sagues; Rosato and Stellin).

Simulations of N Application Alternatives

Crop and soil/water simulations considered representative characteristics of the watershed. A peanut production unit in the northwestern section of the watershed was selected as the representative farm type. Peanut crops rotate with grain corn annually in this example case. Only corn production employs nitrogen fertilizer applications, because peanuts are leguminous. Other chemical applications, including phosphate and potash fertilizers and use of pesticides, are assumed by the simulators to be optimal for
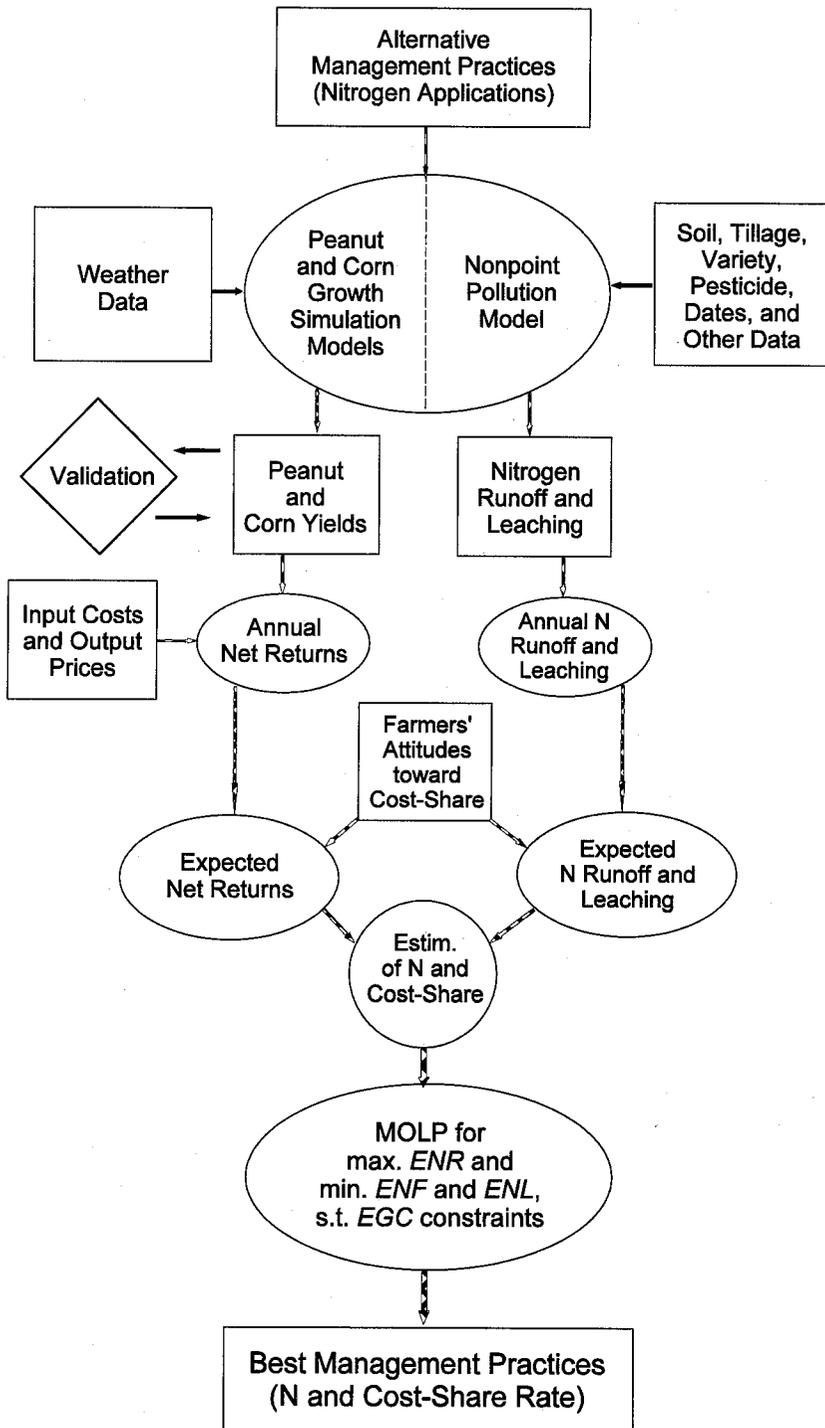
Figure 1. Framework for MOLP modeling of best management practices

Table 1. Net Returns and Soil and N Losses for Low N Application Alternatives

Key Variables	Nitrogen Fertilizer (lbs./acre)					
	24	36	48	60	72	84
Expected Net Returns ($/acre)	67.30	84.60	100.30	113.00	122.30	130.40
Soil Loss (tons/acre/year)	5.56	5.56	5.56	5.56	5.56	5.56
N Loss in Runoff (lbs./acre)	1.88	1.90	1.91	1.92	1.93	1.94
N Loss in Leachate (lbs./acre)	48.33	49.78	51.57	53.40	55.05	56.96

the crop growth conditions. Nitrogen is assumed to be applied twice in a cropping season—one-third of the total amount at sowing date, and two-thirds 30 days later.

Tifton, Georgia, weather data were used in the simulations because Tifton is the nearest station with complete weather records (Hook), and long-term simulations are considered important for weather (Thomas et al.) and risk analysis. Tifton loamy sand, with an average slope of 3%, represents the only soil type used in the simulations (Knisel et al.; Thomas et al.). The locally validated GLEAMS model (Knisel et al.) uses the same weather, soil, crop planting, and management data (such as the nitrogen fertilizer application), and generates predicted nitrogen in runoff, nitrogen leaching, and soil losses as pollution output parameters.

To validate the simulated crop yields, we used 10-year (1982–91) historical peanut and corn yields of Crisp County as observed data for comparison to the simulation output. Annual base model simulations used no irrigation and a rate of 72 pounds of nitrogen fertilizer (Georgia Cooperative Extension Service 1992a). Initial soil conditions were appropriately adjusted (Hook) to modify the simulated yields until simulated 10-year yields closely matched the observed yields. Paired comparisons of means of both simulated and actual yields tested equal at a statistically significant level of 5% using the t-test. Validated base crop models were then used to predict annual crop yields based on a 17-year (1975–91) daily weather record and other management alternatives.

Several agricultural price patterns and expected price patterns exist in south Georgia. Following Chavas, Pope, and Kao, futures prices of corn are collected for the December contract at the Chicago Board of Trade when observed just prior to March 15. Since peanuts do not have a futures market, peanut program quota prices were used as expected seasonal prices. All price levels are adjusted to real 1992 prices by the Producer Price Index. Costs of chemicals and other production processes are based on data from "Crop Enterprise Cost Analysis: South Georgia 1993" (Georgia Cooperative Extension Service 1992a). The annual net return is defined as annual total revenue minus total costs (variable plus annualized fixed costs) of the enterprise under each management scenario.

In order to examine N application alternatives, crop yields and pollution parameters with six different N levels distributed around the 72-pound N base model are simulated, and annual net returns are then computed (table 1). As expected, net returns, nitrogen loss in runoff, and leachate increase with greater N fertilizer rates within this range, while soil loss remains relatively stable. While these variables show approximate linear

relationships with the N fertilizer rate, it should be noted that N leaching increases proportionately less than N application rates. Nitrogen leaching would be 48.3 pounds/acre even if only 24 pounds/acre of N fertilizer is applied. This outcome implies that N fertilizer is not the only source of N leaching. In fact, the N fixation of peanuts can generate significant nitrogen residuals in the soil.

Estimation of Objective and Constraint Functions

A survey conducted in the Gum Creek Watershed included questions eliciting farmers' adoption probabilities for four government cost-share subsidy rates (i.e., rates of 20%, 40%, 60%, and 80%). Each of 29 sampled farmers responded to questions related to their willingness to accept payments in the four cost-share programs outlined in the survey, providing 116 observations of their probability of participation, p. Five different management practices, simulated with N application rates of 72 pounds N per acre (the Cooperative Extension recommended rate on corn for the area concerned) or less (as shown in table 1), provided 580 randomized samples of expected outputs for new management options which generate the same or less N pollution than the base. Expected net returns, pollution parameters, and government costs were then estimated as functions of the amount of N fertilizer applied and prospective government cost-share rates (k) using regression analysis. The estimated coefficients of these decision variables (N application rate and cost-share rate) had the expected signs and were statistically significant (Sun, pp. 56 ff).

We used these participation-based estimators as the set of coefficients to define the dependency of each equation, *ENR*, *ENF*, *ENL*, and *EGC*, on N application management and government cost-share rates for the multiple-objective linear programming (MOLP) as objective and constraint functions, respectively. The MOLP solution procedure was then used to search for the optimal N management and government cost-sharing strategy.

MOLP Solutions

The GCW project targets management of optimal nitrogen fertilizer usage given a particular cost-share rate. Because current N application control targets are not well defined for the area, the *ENF* and *ENL* can be set as objective functions to be minimized, instead of as constraints, in the MOLP. The MOLP problem would then use the estimated functions of *ENR*, *ENF*, *ENL*, and *EGC* to find efficient points for maximizing *ENR* and jointly minimizing *ENF* and *ENL*, subject to the constraints of *EGC* (i.e., less than or equal to the government payment limit).[3] We used ADBASE (Steuer 1992) to enumerate efficient extreme points and unbounded efficient edges by a vector-maximum algorithm for MOLP-type problems.

Setting the government budget constraint at $5 per acre, as the pilot project planned, ADBASE provides three efficient extreme points (table 2), where N fertilizer application ranges from 40.9 pounds to 72 pounds per acre. Of the three efficient extreme points,

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[3] No change in yield of *ESL* accompanied simulated changes in management alternatives (as shown in table 1); thus an *ESL* equation was excluded from the MOLP solutions in this case.

Table 2. Efficient Extreme Points of MOLP Solved by ADBASE

Variables	Option Number		
	1	2	3
N Fertilizer (lbs./acre)	40.9	69.2	72.0
Cost-Share Rate (%)	20.0	80.0	80.0
Expected Net Returns ($/acre)	109.45	125.78	**126.67**
Expected N in Runoff (lbs./acre)	**1.91** (99.0%)	1.92 (99.5%)	1.93 (100%)
Expected N in Leachate (lbs./acre)	**52.66** (96.3%)	54.64 (99.9%)	54.87 (100.3%)
Expected Government Cost Share ($/acre)	5.00	5.00	4.05

Notes: Boldfaced figures denote the best outcome of the variable in the three options. Percentages in paren-
theses represent a comparison of the pollution parameters to the baseline solution (which is estimated at
72 pounds of N and no subsidy).

option 3, which uses 72 pounds of N, appears unrealistic and redundant (no change from
current/base rate of fertilizer application). Option 1, which uses 40.9 pounds of N, is an
efficient point, with the lowest N in runoff and leachate and a cost-share payment of $5
per acre. However, farmers suffer significant losses of expected net revenue. Compared
to options 1 and 3, option 2 reflects an efficient compromise vector: producers apply 69.2
pounds of N fertilizer to corn, and the government shares $5 of the cost of adopting the
new practice. This result attains a significantly higher *ENR* than in option 1, and N
emissions would be less than in option 3.

Decision makers must weigh which efficient option would be the best management
practice when maximum allowable N runoff and leaching are not clearly defined. For
example, if the reduction of N leaching from 54.9 pounds/acre to 52.7 pounds/acre is not
critical with respect to environmental criteria, then 72 pounds of N would be the
preferred BMP. However, option 1 would be the recommended BMP if N leaching is
to be minimized under the current crop mix. In that case, N leaching is reduced by
3.7% per acre, and the government shares 20% of the costs at $5 per acre, while unit
area net returns (including the government payment) would be reduced by $17.22 (or
13.6%) per acre. Nitrogen in runoff and soil losses would be little different for any of the
options.

We next used MOLP to search for efficient management options under varying
government cost constraints. Table 3 compares the optimal solutions for minimizing N
leaching if the government budget were to be restricted to $0 (no payment), $2.50, $5,
$7.50, and $10 per acre, respectively. Expected net returns could decline by a significant
amount when participants start to adopt the cost-share programs. The first $2.50 per
acre of government subsidy could reduce N leaching as much as 2.7%, while unit area
net returns are reduced by $11.91/acre (or 9.6%). *ENR* declines when the government's
shared costs increase, because participating farmers' shared opportunity costs also
increase. As participating farmers and government both pay more, the N leaching from
the crop growth processes decreases slightly and environmental benefits are gained.

Table 3. Optimal Solutions with Four Nonzero Government Budget Constraints

Variables	Government Budget Constraints ($/acre)				
	0	2.50	5.00	7.50	10.00
N Fertilizer (lbs./acre)	72.0	48.1	40.9	33.6	26.3
Cost-Share Rate (%)	0.0	20.0	20.0	20.0	20.0
Expected Net Returns ($/acre)	123.71 (100%)	111.80 (90.4%)	109.43 (88.5%)	107.10 (86.6%)	104.74 (84.7%)
Expected N in Runoff (lbs./acre)	1.929 (100%)	1.917 (99.4%)	1.913 (99.2%)	1.909 (99.0%)	1.906 (98.8%)
Expected N in Leachate (lbs./acre)	54.71 (100%)	53.26 (97.3%)	52.66 (96.3%)	52.06 (95.2%)	51.46 (94.1%)

Note: Percentages in parentheses represent a comparison of the *ENR* and pollution parameters to the outcome of a no-subsidy solution.

When government increases its lump-sum shared cost from $2.50 to $5 per acre, the efficient solution would further reduce N leaching only 1%. Unit area expected net returns are further reduced by $2.36 per acre, after including the government payments. The trends of N leaching declines and expected net return reduction could approximately extend until government shared cost increases to $10, when N leaching is reduced to 51.46 pounds/acre (a decrease of only 5.9% from the no-subsidy case). This projection would provide an overview of the prospects for every dollar of government investment in the GCW voluntary cost-sharing program for fertilizer management.

Conclusions and Implications

Nonpoint pollution production functions and farmers' risk attitudes are two key aspects of the economics of voluntary participation and the resultant impacts of a cost-sharing water quality program. Development of emission-yield simulators has created an opportunity to supply predicted values for missing data (Moxey and White) and avert excessive field measurement costs by establishing nonpoint pollution production functions. These functional relationships allow economically efficient policies to be based upon those production activities which generate potentially polluting emissions. Coupled with information on likelihood of participation, simulation results can predict area-wide emissions reduction and the resultant economic impacts of altered management practices.

This study has integrated three biophysical simulators to predict crop and emission yields, estimated producers' net returns, and water-soil pollution parameters under uncertain weather conditions. Farmers' attitudes toward participation with alternate government cost-share rates were combined in a pollution-abatement BMP analysis. Multi-objective linear programming provides a set of economically efficient solutions for BMPs under current nonirrigation practices, given that there are no well-defined pollution restrictions and that the trends of the expectations on management

parameters are linear. The determination of preferred management practices must weigh environmental criteria and economic costs from the multiple-objective solutions, as pollution-minimizing solutions are very costly for both the public and individual farmers.

In the case of Georgia's Gum Creek Watershed producers, expected net returns would decline an estimated 9.6% upon partial voluntary adoption of a cost-share management program with a $2.50/acre subsidy. Nitrogen leaching would be reduced by 2.7%. For every additional $2.50 government payment in the cost-sharing program, expected nitrogen leaching is reduced by 1.1%, while area producers endure further losses of about $2.36/acre from prior expected net returns. Reducing nitrogen leaching in the GCW is extremely expensive to agricultural producers and the government alike, when solutions require current cropping patterns and land use. Stricter nitrogen pollution-abatement strategies might need to consider change of crop rotation or other options beyond the fertilizer application practices contracted in this pilot study.

Those producers who voluntarily participate in such a cost-sharing, incentive-based program are likely more risk averse than average. That is, their risk premium is likely larger than average, or they would not be inclined to accept partial payment for reductions of practices that lead, on average, to lower net returns. Because fertilizer application to nonirrigated corn is risk-increasing, the reduction in fertilizer use might be greater than that indicated in this study. Potential participants may be willing to pay larger own-share premiums than those suggested by the means presented in our analysis. This would imply a greater return to the program than predicted here. Such a hypothesis would require testing over a greater range of prospective participants than was possible in this pilot study. However, since actual measurement/monitoring of non-point emissions on a large scale is not feasibly practical, cost-sharing incentives do offer self-targeting, pollution-abatement strategies to efficiently manage nonpoint emissions toward publicly targeted levels while distributing the uncertainty costs among all potential water users.

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