COST-SHARING INCENTIVES IN THE GUM CREEK WATERSHED AGRICULTURAL WATER QUALITY PILOT PROJECT

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Abstract. Analysis of farmers' attitudes and potential and predicted responses to cost-sharing incentives is key to prospective adoption of such a program on a wider scale. A pre-project survey of potential participants in the Gum Creek Watershed, and an economic evaluation of management alternatives found that voluntary participation improved with higher cost-sharing rates. However, nitrogen runoff leaching effects were limited. Biophysical simulation and mathematical programming indicate that profit-enhancing changes in supplemental irrigation management cause little or no added impact on water quality. Decreasing the nitrogen applications from currently advised rates has limited abatement potential because it sharply decreases farmers' expected net returns and voluntary participation. This analytical framework provides critical decision-making information on the economic and environmental tradeoffs and burdens under variations of program implementation. The analytical framework can be applied to other agricultural areas for prospective pollution abatement policies with regard to the same or other agricultural practices.

INTRODUCTION

The Gum Creek Watershed (GCW) comprises approximately 21,200 ha in the Coastal Plain of Georgia. A state nonpoint assessment report and nonpoint source management plan identified Gum Creek as an agricultural stream likely to be threatened by agricultural nonpoint source pollution, and the watershed was subsequently selected as one of 16 water quality demonstration projects nationwide in which to examine potentially polluting agricultural practices (GCES, 1992b). Georgia legislation protects the "public interest" for "beneficial use" of riparian water resources (Wright, 1984, p. 20) while establishing a class of "high value" users of water resources with non-riparian rights (Smith, 1978). Traditional riparian property rights, however, may require that the public share farmers' costs for nonpoint source pollution abatement.

The GCW project aspires to reduce potential nonpoint source pollution by inducing farmers to voluntarily adopt "best management practices" (BMPs) within a federal cost-sharing pilot program (GCES, 1992b). This paper reports a study which evaluates the potential for voluntary adoption of BMP alternatives by assuming, prior to the implementation of the project, that the federal government would share a portion of the production opportunity costs of abatement with participating farmers. The analytical framework is introduced next, followed by the results of simulations and predicted responses to varying government payments. Conclusions to the analysis incorporate policy implications based on the Gum Creek case.

ANALYTICAL FRAMEWORK

The objective of this study was to develop an analytical framework and assess potential chemical and irrigation management practices which could reduce ground and surface water pollution while retaining farmer profitability under a public/private cost-share program. Figure 1 presents the schematic of the analytical framework which we developed. The analytical approach integrated (a) peanut and corn crop growth simulation models, (b) a soil/water simulation model, (c) estimation of expectations of farmers' net returns and pollution levels associated with alternative management practices, and (d) mathematical programming to evaluate nitrogen and irrigation management for an area-representative, profit-maximizing farm.

Chemical and irrigation management practices can be altered to reduce soil erosion and nitrogen nonpoint pollution resulting from crop production. These two management practices embody the primary BMPs contracted in the GCW project and form the basis of the scenarios evaluated. Economic modeling of agricultural production in the GCW started from the assumption of maximization of farmers' expected net returns to the land when agricultural source pollution is restricted to allowable levels under current production technology conditions (Sun, 1994; Griffin and Bromley, 1982). Abatement from current practices would be compensated partially by government lump-sum subsidies to farmers.

Three locally-validated, biophysical simulators were linked and utilized to obtain crop yields and pollution output. Simulated output was used to overcome the problem of missing measurements of water quality data. We simulated and predicted peanut crop development, water and nitrogen balance, and the final peanut yield using PEANUTGRO version 1.02 (Boote *et al.* 1989), a process-oriented peanut crop growth model. CERES-Maize version 2.10 (Ritchie *et al.* 1992) simulated the growth and yield of corn, produced in rotation with peanuts. GLEAMS version 2.0 (Knisel *et al.* 1992) simulated the physical movement of agricultural chemicals within and through the plant root zone and produced the chemical pollution and soil erosion output levels, given crop growth parameters, agricultural management systems, and other physical data.

Simulations of Irrigation Application Alternatives

Peanuts, cotton, pecans, pasture, melons, and corn constitute the major crop activities in the watershed. Using information gathered from individual farmer surveys (GCES 1992a), our crop and nitrogen runoff/leaching simulations considered site-specific characteristics of the watershed. We selected a peanut farm in the

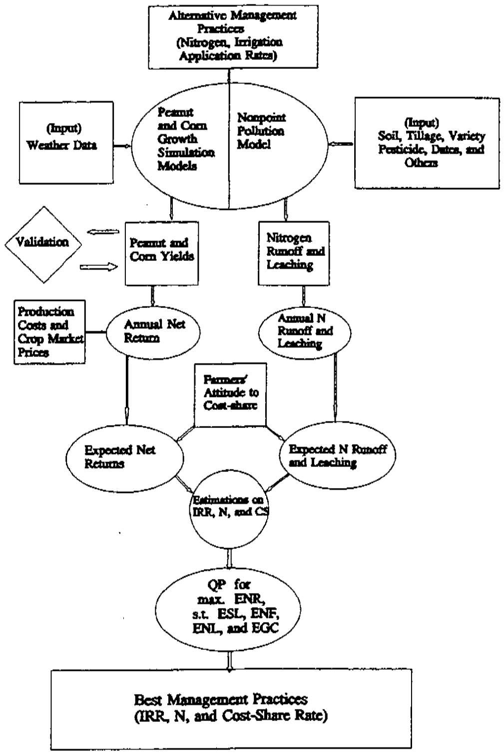

Figure 1 Data Flow in Modeling Best Management Practices

northwestern section of the watershed as a representative farm type and site. Because long-term simulations are important for incorporating weather (Thomas *et al.* 1990) and market risk into the analysis, 17 years' (1975-1991) daily observations of Tifton weather data were used in the simulations. Tifton loamy sand with an average 3% slope represented the soil characteristics used in the simulations (Knisel et al., 1991; Thomas et al., 1990).

Design Conditions

We modelled peanuts rotated annually with corn, representing the mix of other crops for this area. Only corn production employs nitrogen fertilizer applications, and other chemical applications, including phosphate and potash fertilizers and the use of pesticides, were assumed at optimal rates for the crop growth conditions. Approximately 25% of the cropping land currently receives supplementary irrigation. In the simulations, supplemental irrigation was triggered each time in the growing season when water content in the soil (at 50 cm in depth) was detected to drop to specified percentages.

Previous ten-year (1982-1991) peanut and corn yields of Crisp County (in the GCW) were used as observed data for comparison and validation of the simulated crop yields. Initial soil conditions were appropriately adjusted to modify the simulated yields until they closely matched the observed yields (Hook, 1991).

Management Alternatives.

Base model simulations used no irrigation and a rate of 81.7 kg/ha of nitrogen (N) fertilizer (GCES, 1992a). Validated base models were then extended to generate predicted annual crop yields and N emissions under current (baseline) and alternative nitrogen fertilizer application and supplementary irrigation management practices. Farmers' net returns were calculated using corresponding market-year price data. As the irrigated growth parameters demonstrated nonlinear relationships (Sun, 1994), we used quadratic programming (QP) to search for economically optimal management practices (BMPs).

Estimation of Objective and Constraint Functions

In a voluntarily adopted cost-share program, farmers' attitudes toward adoption of the program will determine their expected net returns and the expected pollution levels, as well as the expected government expenditures on the cost-sharing program. The incentive program in this case was assumed to be based on a lump-sum sharing of the farmer's reduction of net returns (opportunity costs) by adopting the new alternative. Then the expectations of the area-wide, representative GCW net returns (ENR), soil losses (ESL), nitrogen losses by runoff (ENF), and nitrogen losses by leaching (ENL) sum both voluntary adoption and non-adoption possibilities. For example, let a farmer's probability of adopting current management be $(1\text{-}p)$, with net return R_0. That same farmer's probability of adopting the new management practices is p, with net return R_1 plus the government cost-sharing payment, $\Delta R\, k$. The summation of both possibilities, $(1\text{-}p)R_0 + p(R_1 + \Delta R k)$, then represents the GCW farmer's ENR. Expected pollution levels likewise sum outcomes of each alternative multiplied by its respective probability.

Information on farmers' willingness-to-accept payments for reducing production levels and the corresponding chemical applications was collected in the GCW survey in order to enumerate farmers' adoption probabilities for four government cost-share rates, 20%, 40%, 60%, and 80%. Simulated net returns and potential pollution effects with regard to six N and five irrigation application alternatives in each of 17 years' weather data were then combined with the farmers' attitudes toward the cost-share rates to generate randomized (weather and market) annual expectations of net returns and potential emission levels. Coefficients for the expectations of outcomes of the management alternatives were estimated from regressions of the expectations on the nitrogen, irrigation, and cost-share rates. Second-order Taylor series equations were used to approximate the nonlinearity of the expectation responses to the management alternatives. Regression results provided reasonable estimates of objective and constraint function parameters for the economic optimization of management alternatives.

Given voluntary participation in a cost-sharing program for controlling agricultural nonpoint source pollution with irrigation management options, deterministic mathematical programming techniques can be used to optimize management practices and cost shares. The nonlinearities of the maximization problem required a nonlinear programming model approach. Formulating the problem using QP, the objective function was stated:

$$\text{Max: } ENR(IRR, N, CS)\ ,$$

subject to:

$$ESL(IRR, N, CS) \leq SL^*\ ,$$
$$ENF(IRR, N, CS) \leq NF^*\ ,$$
$$ENL(IRR, N, CS) \leq NL^*\ , \text{ and}$$
$$EGC(IRR, N, CS) \leq GC^*\ ,$$

where IRR represents irrigation treatments, N is nitrogen application rate, and CS the cost-share percentage. SL*, NF*, and

NL* are the target levels (restrictions) of soil loss, nitrogen runoff, and nitrogen leaching, respectively. GC* is the government cost share or the government budget constraint. GAMS (General Algebraic Modeling System)/MINOS (Murtagh and Saunders, 1987; Brooke *et al.*, 1988) was used to solve the QP problem.

RESULTS

Baseline Model

Given the cropping rotation modelled, an option using 122.7 kg/ha of N and supplemental irrigation triggered at 50% soil water content could increase farmers' average expected net returns (ENR) from $305.8/ha (under the current practice of 81.8 kg/ha N and non-irrigation) to $648.3/ha, a 112% increase. Resultant soil losses would increase less than 0.4%. The N runoff would increase by 0.11 kg/ha, or about 5.0%, while N leaching would increase by 8.9 kg/ha, or 14.2%. If pollution effects could be ignored (that is, if the resultant effects were less than or equal to GCW area targets set for nonpoint pollution by the EPA), the potential profitability of this supplemental irrigation option is substantial. Simulated N leaching declines slightly from baseline when irrigating at the 20% water availability irrigation before increasing at higher irrigation rates. In contrast, the case of no irrigation and zero N fertilizer application found that N leaching could be reduced 18.1% and N runoff by 2.3% from the baseline. Thus, agricultural sources of potential water quality degradation or enhancement could be altered only within a rather limited range of response by employing these fertilizer and irrigation management practices.

Current pollution control targets, which would comprise a generally-acknowledged environmental criteria set, did not exist for comparison with the simulated soil and N pollution outputs. However, pollution control targets must be set in the analysis of management practices designed to reduce emissions. In the baseline model, the soil losses and N emission levels were restricted to levels less than or equal to the pollution levels corresponding to the management alternative with 122.7 kg/ha of N and a 50% water availability level. This option had the highest simulated ENR and was accompanied by a predicted soil loss of 12.68 t/ha, N runoff of 2.30 kg/ha, and N leaching of 71.5 kg/ha. If the maximum government cost-share payment was limited to $0/ha (no payment) in the baseline solution, a farmer would obtain $644.28/ha net returns on peanut/corn crop land. Soil losses and N runoff and leaching remained equal to or below constrained levels, closely approximating the management alternative derived directly by simulation results.

Sensitivity Analysis of BMPs

We then modeled the economic sensitivity of pollution abatement and the corresponding cost-share programs over a range of management alternatives. Only one emission target or government cost constraint was changed in each scenario by a specific percentage from the baseline model, leaving other constraints unchanged (Table 1). Optimization results showed that nitrogen leaching could be expected to be reduced by up to 10% from baseline results over the range of incentives tested. Soil losses and nitrogen runoff were quite inflexible with respect to abatement potential. The N fertilizer and irrigation applications, as well as farmers' ENRs, declined as stricter environmental criteria were imposed.

Table 1 displays the predicted parameters of BMP alternatives for each additional 2.5% N leaching reduction. For example, when N leaching was reduced by 2.5% from the baseline model, the N fertilizer application must be reduced by 15.6 kg/ha. Irrigation triggering would drop from the 46.5% to 45.9% soil-water content. Farm ENR losses, after receiving the subsidy payment, approximated $3.75/ha. However, when N leaching was curtailed another 2.5%, N fertilizer must be further reduced by 18.2 kg/ha and the irrigation triggering level lowered by 0.8%. Further farm ENR losses were $5.88/ha for the additional 2.5% N leaching reduction from this lower initial level.

With a federal budget restriction imposed at the current maximum of $12.50/ha, the government's cost-share rates decreased as stricter pollution criteria were imposed. Consequently, the farmers' ENRs also were reduced in the feasible scenarios. Thus the farmers' voluntary adoption rates declined. Assuming the budget restriction remained at $12.50/ha for the government's cost share, all QP solutions in Table 1 were feasible to farmers with no less than a 20% government cost-share rate. For example, if N leaching were to be reduced by 2.5%, government could share the cost of reduction at a 61.2% rate within the budget limitations and farmers could expect $643.23/ha net returns. However, if N leaching must be reduced by 10%, the government share covers only 36.1% of the expected losses, and the farmer's ENR would be reduced by $28.08/ha. Farmers' adoption probabilities would be reduced correspondingly.

CONCLUSIONS AND IMPLICATIONS

The Gum Creek Watershed Pilot Cost-Sharing Project instituted an incentive-based program to abate nitrogen leaching and runoff from agricultural sources. Farmers' attitudes and potential and predicted responses to cost-sharing incentives are key to wider-scale adoption of such a program. A pre-project survey of potential participants and an economic evaluation of management alternatives found that although voluntary participation improved with higher potential cost-sharing rates, nitrogen runoff and leaching effects were limited.

Biophysical simulation and mathematical programming suggest that changes in supplemental irrigation management may offer more-profitable and less uncertain opportunities with little added impact on water quality. Irrigation and nitrogen fertilizer applications do not alter the water quality as much as generally anticipated, according to simulated results. However, decreasing nitrogen applications from currently advised rates sharply decreases farmers' expected net returns, voluntary participation, and has limited abatement potential.

The costs of agricultural pollution abatement by reducing irrigation and/or nitrogen fertilizer application are high and increasing at the margin. Other nonagricultural sources or other agricultural practices, including restricting the cropland for peanuts in the rotation, appear to hold promise of significant water quality enhancement. Under limited government payments, pollution abatement significantly reduces farmers' net revenues. Hence, without increased threats of other regulatory means, more farmers would opt out of the program. This analytical framework provides critical decision-making information on the tradeoffs and burdens under variations of program implementation and can be applied to other agricultural areas for prospective pollution abatement policies with regard to the same or other agricultural practices.

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Table 1. Sensitivity of Expected Outcomes to Alternate Pollution Targets

Constraint Changes from Baseline		Management Variables			Expected Net Values*				
Constraint	Change %	Irrigation %	Nitrogen kg/ha	Cost Share %	Returns %	Soil Loss %	Nitrogen Runoff %	Nitrogen Leaching %	Gov't. Payment $/ha
Soil Loss	-0.1	13.7	124.3	20.0	95.7	99.9	99.9	100.0	8.95
N Runoff	-1.0	28.7	43.8	20.0	95.6	100.0	99.0	89.6	9.83
N Leaching	-2.5	45.9	109.9	61.2	99.8	100.0	99.9	97.5	12.50
N Leaching	-5.0	45.1	91.7	57.7	98.9	100.0	99.4	95.0	12.50
N Leaching	-7.5	39.6	73.8	51.1	97.5	100.0	99.4	92.5	12.50
N Leaching	-10.0	33.0	51.3	36.1	95.4	100.0	99.4	90.0	12.50

*Note: The expectations, except EGC (federal payment), are compared to the baseline solutions, simulated at 122.7 kg/ha of N and a 50% soil-water availability for irrigation.