HENGLUN SUN AND JACK HOUSTON*

Economic Analysis of Best Management Practices in a Pilot Cost-Sharing Water Quality Program

Abstract: Simulated crop growth and nonpoint pollution yields under stochastic weather conditions generated farmers' expected net returns and the environmental effects of implementing 'Best Management Practices' (BMPs) under risky and uncertain conditions. Results from varying nitrogen fertilizer and irrigation management levels over a growing season show that, for production-optimal levels of nitrogen fertilization and irrigation without regard to pollution, nitrogen leaching is more serious, but soil loss and nitrogen runoff are lower, than for other scenarios tested. Voluntary implementation of BMPs to reduce levels of inputs and decrease water quality impacts would require substantial cost-sharing incentives. Farmers favour a cost-sharing program, with 87 percent willing to participate when government's cost-share is at the 80 percent level. When tight budgets restrict implementation of stricter pollution targets, a 20 percent cost-sharing would induce 27 percent of the farmers surveyed to voluntarily select BMPs.

INTRODUCTION TO THE GUM CREEK WATERSHED WATER QUALITY PROGRAM

Water quality pollution generated by agricultural production practices is regarded among the major environmental problems of the 1990s. The Gum Creek Watershed (GCW) in South Georgia was selected as one of 16 water quality demonstration projects in the US in which to examine potentially polluting agricultural practices. The Gum Creek Water Quality Project aims to reduce potential nonpoint source pollution by inducing farmers to voluntarily adopt 'best management practices' (BMPs) within a federal cost-sharing pilot program. This study compares activity levels through Multiple Objective Programming (MOP) analysis to search for economically optimal BMPs.

Gum Creek Watershed comprises approximately 53 000 acres in the coastal plain of Georgia. Average annual rainfall is 45 inches, generally well-distributed over the growing season. The topological relief in the area is gentle, with broad valley floors and 2 percent to 5 percent slopes dominating uplands. Tifton-Dothan-Raines and Tifton-Alapaha-Dothan are the dominant soil associations, while the dominant surface texture is loamy sand. Intensive agricultural production typifies land use in the watershed, with a diversity of crops produced. Several subwatersheds commonly plant more than 50 percent of their surface area to crops that have high fertilizer and/or pesticide requirements. Peanuts, the major crop in the watershed, comprises 5013 acres; other crops include soybeans, cotton, pecans, pasture, melons, and corn. In 1991, 25 percent of cropland in the watershed was irrigated using diverse systems. Soils with high or intermediate pesticide and nutrient leaching pollution potential cover most upland of the watershed (CGES, 1992).

* University of Georgia, Georgia, USA.

ANALYTICAL FRAMEWORK

Integrated Crop Management and Irrigation Water Management exemplify the two major BMPs analyzed in the economic evaluation of this project. Using results of individual farmer surveys in the GCW, we model a representative farm in the watershed to provide the framework for economic analysis of cost-sharing incentives to alter levels of fertilizer application and irrigation management. All related data — including topography, soil, weather, crop production and management practices, market prices and costs — were collected from project surveys and the Cooperative Extension Service (CES). The integrating approach for this analysis links (a) peanut and corn crop simulation models to predict crop yields under alternate (input) management practices, (b) selected water pollution and soil erosion simulation models to predict pollution levels, and (c) multiobjective programming analyses to assess irrigation and nitrogen management measures under risk and uncertainty for a representative profit-maximizing farm.

PNUTGRO version 1.02 (Boote *et al.*, 1989), 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.*, 1992) simulates the growth and yield of corn, produced in rotation with peanuts. GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) version 2.0 (Knisel *et al.*, 1992), is selected to physically simulate agricultural management systems relating the movement of agricultural chemicals within and through the plant root zone and produce the chemical pollution and soil erosion output levels. A 100-acre peanut farm is simulated for the northwest sector of the watershed, using representative weather data (i.e., rainfall, temperature, and solar radiation data) from Tifton (Hook, 1991), the nearest weather station. Tifton loamy sand on average 3 percent of slope represents the soil type (Hook 1991, Knisel *et al.* 1991; and Thomas *et al.* 1989). The peanut crop typically rotates with grain corn annually. Only corn requires appreciable nitrogen fertilizer, because peanuts are leguminous. Other chemical applications, including phosphate and potash fertilizers, and varied use of pesticides are optimized by the simulators. 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. Irrigation levels in the simulator are controlled by detection of the threshold soil water at a 0.50 metre depth, based on the calculations of the day-by-day soil water balance. GLEAMS uses the same weather, soil, crop planting, and management data, with irrigation water data imported from crop growth models and merged to the precipitation data files of GLEAMS day-by-day, to generate the pollution output parameters.

Ten-year (1982-91) peanut and corn yields of Crisp County validate the models, as in Hook (1991), with initial soil conditions appropriately adjusted to modify the simulated yields until simulated ten-year yields closely match the observed yields (i.e., paired comparisons of means of both simulated and actual yields tested equal at a statistically significant level of 5 percent using the t-test). Base models use no irrigation and a rate of 72 pounds of nitrogen fertilizer (CES). Validated base crop models are then extended to generate annual crop yields with the past 17-year weather data. Following Chavas *et al.* (1983), futures prices of corn are collected for the December contract when observed just prior to March 15 at the Chicago Board of Trade. Prices of peanuts, which do not have a futures market, cite peanut program quota prices as expected seasonal prices. All price levels are adjusted to real 1992 prices by the Producer Price Index. Costs for irrigation and chemical usage are based on CES (1993), with nitrogen fertilizer and irrigation costs computed to changing application levels and unit prices. The expected net return is defined as total expected revenue minus total costs (variable plus annualized fixed costs) of the enterprize under each management scenario.

To test the sensitivity of farmers' returns and pollution levels, differing amounts of nitrogen application are selected. One expects ENR to rise as nitrogen fertilizer application rates increase. However, while soil losses change very little among the management practices, nitrogen runoff losses grow quite measurably and nitrogen also much more likely percolates into ground water with increasing fertilizer usage and no irrigation (Table 1). Thus, maximizing farmers' expected annual net returns is not a sufficient criterion for a BMP. If all pollution levels that resulted from a management practice with the highest expected net return are below the environmental pollution target criteria, the management practice can be defined as BMP. However, if some pollution level generated from the management practice exceeds the environmental target, the management practice should be changed. A new alternative that meets the environmental criteria and has the least reduction from the highest return would be selected BMP. The reduction in expected net returns is then the opportunity cost, or loss in net returns, of implementing the BMP. The representative farm would attain, on average, a \$122 annual baseline ENR per acre at a rate of 72 lb. of nitrogen fertilizer usage while generating over 55 lb. of nitrogen leaching (Table 1).

Table 1 *Net Returns and Pollution Yields (per acre-year) for Low N Application Alternatives*

	Nitrogen fertilizer (lb)					
Key variables	24	36	48	60	72	84
Expected net return (\$)	67.3	84.6	100.3	113.0	122.3	130.4
Soil losses (t)	5.56	5.56	5.56	5.56	5.56	5.56
N losses by runoff (lb)	1.88	1.90	1.91	1.92	1.93	1.94
N losses by leaching (lb)	48.33	49.78	51.57	53.40	55.05	56.96

Farmers' Optimal Cost-Sharing Program

The optimal cost-sharing program can be considered by both farmers and government as a question of costs and benefits. The government decision is supported by their estimation of the potential environmental effect by a specific percentage of farmers implementing the BMP and by budget availability. However, farmers' attitudes toward the cost-sharing program are quite diverse, owing to their current management practices, their risk attitudes toward environmental problems, and their perceptions of a new program. Suppose current management practice generates annual net return A for a farmer and a new BMP would reduce the net return to B. Under a cost-sharing program, assuming each farmer has a p probability of adopting the new BMP and taking a k share subsidy from government (i.e., cost of the program $= A - B$) for doing so, the expected annual net return (ENR) for the farmer would sum the expectations of the net returns from two cases-maintaining current practice versus an altered practice (the BMP). That is,

$$(1)\quad ENR = E(A) + E(B) = (1-p)A + p[B + k(A-B)]$$

By algebraic manipulation, the expected net return is transformed:

$$(2)\quad ENR = A - p(1-k)(A-B)$$

A and B can be estimated and are considered constant in the cost-sharing decision procedure for a specific BMP. An optimal cost-sharing percentage can, from the farmer's perspective, be decided by the highest *ENR*, which would be determined by the term $p(1-k)$. Call that term the share parameter. The higher the value of the share parameter, the lower the *ENR* would appear, and the cost-sharing percentage would be less favored by farmers.

Table 2 *The Share Parameters for Cost-Sharing Program Alternatives*

Cost–sharing percent by Government *(k)*	Mean probability of adoption by farmers *(p)*	Share parameter *(p(1–k))*
80%	87%	0.174
60%	70%	0.280
40%	45%	0.270
20%	27%	0.216

Individual farmer surveys in the Gum Creek Project area provide the farmers' attitudes towards several alternatives of government cost-sharing levels and indicate the program could be helpful in approaching an optimal cost-sharing program. The questionnaire was designed to collect information about farmers' management practices, their attitudes toward environmental pollution and toward a cost-sharing program, as well as their socio-economic background. An estimated 61 farmers operate 70 farms in the Gum Creek Watershed. Participants' gross farm incomes in 1990 averaged just over $100 000 per farmer, and, on average, they applied 98 pounds of nitrogen per acre (or 110 kg/ha) of corn annually. The probability of their willingness to adopt a government cost-sharing BMP program decreases as government's percentage share declines. Using the mean of the probability of participation to represent farmers in the watershed, the parameters $p(1-k)$ are shown in Table 2. Since the mean $p(1-k)$ at 80 percent government share, with a mean at 0.174, is the lowest, the 80 percent cost-share level would be the option most favored by the farmers. The 20 percent level of government share, with a mean $p(1-k)$ of 0.216, appears the second most-favorable option. However, the government must consider the potential effect of a higher percentage of farmers staying out of the program and retaining current management practices — higher expected pollution levels.

Multiple Criteria Optimization

The Gum Creek Water Quality Pilot Project poses a multiple-criteria decision-making problem in that it aims to control water pollution while not overly detracting from the maximization of farmers' profits. Multiple-criteria programming 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. That is, a feasible solution must be found such that there is no other feasible solution that can achieve the same or better performance for any one of the objectives without decreasing at least one of the other objectives. Therefore, multiple criteria optimization is equivalent to the concept of economic efficiency, and increasing numbers apply MOP for agricultural planning (Romero and Rechman, 1989; Berbel, Gallego, and Sagues, 1991; Maino, Berdegue, and Rivas, 1993) and resource management (Rosato and Stellin, 1993; Zekri and Albisu, 1993).

Multiple objective linear programming (MOLP) uses a vector-maximum algorithm, which computes an efficient point or points that 'maximize' the criterion vector and satisfy all constraints such that the resultant vector values are not dominated by any other points (Steuer, 1986). However, the 'maximization' of a vector of objectives generates a set of efficient solutions instead of one optimal solution. The entire set of efficient solutions is presented to a rational decision-maker, and he/she then selects the BMP alternative perceived most attractive. The decision maker, by reviewing the list of nondominated criterion vectors associated with the efficient extreme points, can identify his/her efficient extreme point of greatest utility (Steuer, 1986).

Three-fourths of the farmers in Gum Creek Watershed operate without irrigation. In order to examine N application alternatives, eight N levels centered around 72 lb. are simulated without irrigation. Farmers' net returns, nitrogen losses by runoff and leaching will increase with greater N fertilizer levels within this range (Table 1). Since cost-sharing is to be voluntarily adopted, farmers' attitudes toward adoption of the program will determine their net returns and pollution levels, as well as government expenditures. Let p be the farmer's probability of adopting the program in which government shares k percent of the cost of the management activity alternatives under the program. The cost of the program is the reduction in the farmers' net returns from adopting the new alternative, ΔR; i.e., the net return from current management, R_0, less that from new management, R_1, S_0, S_1, F_0, F_1, L_0, and L_1 refer to the soil losses, nitrogen to runoff, and nitrogen leaching from both current and new management practices, respectively. The expectations of farmers' net returns (*ENR*), soil losses (*ESL*), nitrogen losses by runoff (*ENF*) and nitrogen losses by leaching (*ENL*) will be summations of both probabilities. For example, a farmer's probability of adopting current management is $(1-p)$ with net return R_0 and that of new management is p with net return R_1 plus government cost-sharing ($\Delta R\ k$). The summation of both possibilities, $(1-p)R_0 + p(R_1 + \Delta Rk)$, would then be the farmer's *ENR*. The expected pollution levels would sum up outcomes of each alternative multiplied by its probability. The government's expected lump-sum costs (EGC) will also depend on the farmer's attitude toward adopting the program. These expectation functions follow:

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

(4) $ESL = (1-p)S_0 + pS_1$

(5) $ENF = (1-p)F_0 + pF_1$

(6) $ENL = (1-p)L_0 + pL_1$

(7) $EGC = \Delta Rpk$

Table 3 *Regression Results of the Expectations on N Application and Government Cost-Share*

Dependent Vars. / Explanatory Vars.	Expected net returns	Expected N runoff	Expected N leaching	Expected government cost-sharing
Constant	93.83	1.89	49.4	15.8
	(87.4)**	(1223)**	(203)**	(14.5)**
N fertilizer (lb/a)	0.324	0.000524	0.0825	–0.344
	(19.1)**	(21.5)**	(21.5)**	(–20.0)**
Cost share rate (%)	11.9	–0.00385	–0.606	16.3
	(9.26)**	(–2.08)*	(–2.08)*	(12.5)**
Adjusted R^2	0.44	0.45	0.45	0.49

Notes: *t*-values are in parentheses. ** and * indicate significance at 1 percent and 5 percent levels, respectively.

Five different management practices, simulated with 72 lb. N or below, provide expected output for new management options which cause the same or less N pollution. From the 29 farmers responding to four cost-sharing attitude questions in the Gum Creek Farmer Survey, 116 random observations of p are used to generate 580 randomized samples of expectations with respect to five N application alternatives. The expectations samples are then estimated by amount of N fertilizer applied and government cost share (k) using Ordinary Least Squares (Table 3) from varying usages of N fertilizer and government cost-sharing percentages (Equations 3 through 7). All the estimated coefficients have the expected signs and are statistically significant. The estimated functions define the dependency of *ENR, ENF, ENL,* and *EGC* on N fertilizer and government cost-sharing. MOLP uses the estimated functions as objectives and constraint, respectively, to search for an optimal N and government cost-sharing strategy.

Because current N control targets are not well defined, the *ENF* and *ENL* can be set as objective functions to be minimized, instead of constraints, in the MOLP. Thus, the MOLP problem uses the estimated relationships of *ENR, ENF, ENL,* and *EGC*, based on N fertilizer and cost-sharing percentage, to find efficient points for maximizing *ENR* and jointly minimizing *ENF* and ENL, subject to the constraints of government outlays. Substituting the estimated regression coefficients into the objective functions and setting the government budget constraint at $5.00 per acre, as the project planned, the MOLP solver provides three efficient extreme points (Table 4), when N fertilizer application ranges from 40.9 lbs. to 72 lbs per acre. Of the three efficient extreme points, option 3, which uses 72 lb. of N, has the highest ENR and N losses. All farmers would adopt option 3, if current pollution levels would not be a problem. Option 1, which uses 40.9 lb. of N, has the lowest *ENR* and N losses, and it is the most efficient option for reducing N losses to runoff and leaching with government cost-sharing at $5.00 per acre. However, farmers suffer higher losses of *ENR*. Compared to options 1 and 3, option 2 is a compromize point reflecting values other than efficiency. Farmers apply 69.2 lb. of N fertilizer, government shares $5 of the cost, and farmers attain higher *ENR* than option 1, while N losses would be less than the option 3.

Table 4 *Efficient Extreme Points of MOLP by ADBASE*

Variables	Option number		
	1	2	3
N fertilizer (lb/a)	40.9	69.2	72.0
Cost share rate (%)	20	80	80
Expected net return ($/a)	109.45	125.78	126.67
Expected N runoff (lb/a)	1.92 (99.0%)	1.92 (99.5%)	1.93 (100.0%)
Expected N leaching (lb/a)	52.66 (96.3%)	54.64 (99.9%)	54.87 (100.3%)
Expected government cost share ($/a)	5.00	5.00	4.05

Sensitivity Analysis of Government Budget Constraints

Decision-makers must weigh which efficient option would be the BMP when maximum allowable N losses to runoff and leaching are not clearly defined. MOLP can be used to search for optimal management options under varying government cost constraints. Table 5 compares the optimal solutions for minimizing N losses if the government budget were to be restricted to $2.50, $5.00, $7.50, and $10.00 per acre, respectively. The farmers' *ENRs* actually decline as the government's shared costs increase, because farmers' costs proportionately increase. As farmers and government pay more, the N losses to runoff and leaching from the crop growth processes both turn down and environmental benefits are gained. When government increases its lump-sum shared cost from $2.50 to $5.00 per acre, the optimal solution would reduce nitrogen runoff only from 1.917 to 1.913 lb/acre (or 0.2 percent) and N leaching from 53.26 to 52.66 lb/acre (or 1.0 percent). Farmers' expected net returns are reduced by $2.37 (from $111.80 to $109.43) per acre, after including the government payments. Pollution-minimum solutions cost more for both government and individual farmers. It is estimated that for every $2.50 government payment in the cost-sharing program, expected N losses to runoff are reduced by 0.2

percent, and expected N leaching is reduced by 1.5 percent. At the same time, the individual farmer pays (loses) about $2.35 from his prior expected net returns.

Table 5 *Optimal Solutions With Four Budget Constraint Alternatives*

Variables	Budget constraint ($/acre)				
	0	2.50	5.00	7.50	10.00
N fertilizer (lb/a)	72.0	48.1	40.9	33.6	26.3
Cost share rate (%)	55.1	20	20	20	20
Expected net returns ($)	123.71 (100%)	111.80 (90.4%)	109.43 (88.5%)	107.10 (86.6%)	104.74 (84.7%)
Expected N runoff (lb/a)	1.929 (100%)	1.917 (99.4%)	1.913 (99.2%)	1.909 (99.0%)	1.906 (98.8%)
Expected N leaching (lb/a)	54.71 (100%)	53.26 (97.3%)	52.66 (96.3%)	52.06 (95.2%)	51.46 (94.1%)
Expected government costs ($/a)	0	2.50	5.00	7.50	10.00

Note: The figures in the parentheses compare the ENR and pollution parameters to the outcome of a no-subsidy solution.

SUMMARY AND IMPLICATIONS

We simulated crop growth and nonpoint pollution yields under stochastic weather conditions to generate farmers' expected net returns and the environmental effects of implementing various BMPs under risky and uncertain conditions. A cost-sharing program can reduce the N leaching by subsidizing farmers for reducing their nitrogen fertilizer levels by considering benefits and costs of both farmers and other water users (the general public). Comparison of the simulated pollution levels with EPA target levels can be used to optimize the BMPs and find appropriate cost-sharing program incentives. The government decision supports their estimate of the potential beneficial environmental effects that can be attained by a specific percentage of farmers implementing the program subject to budget availability. However, farmers' attitudes to the cost-sharing program can be quite diverse, due to their current individual management practices and to their risk attitudes to environmental problems and a new government program. Survey response analysis shows that farmers favor a program with government's share at 80 percent of cost. A 20 percent government cost-sharing could induce higher expected net returns than those of 60 percent or 40 percent cost-sharing level, although fewer farmers would participate.

The conclusions derived from this research could be very site-specific, because the management alternatives are simulated through specific soil and weather conditions. However, the methodology used in this research could be extended to other geographic areas, as well as other management alternatives for searching the best management practices.

REFERENCES

Berbel, J., Gallego, J. and Sagues, H., 1991, 'Marketing Goals vs. Business Profitability: An Interactive Multiple Criteria Decision -Making Approach', *Agribusiness*, Vol. 7, No. 6, pp.536–49.

Boote, K.J., Jones, J.W., Hoogenboom, G., Wilkerson, G.G. and Jagtap, S.S., 1989, *Peanut Crop Growth Simulation Model: User's Guide (V 1.02)*, Florida Agricultural Experiment Station, Journal No. 8420, May.

Chavas, J.P., Pope, R.D. and Kao, R.S., 1983, 'An Analysis of the Role of Futures Prices, Cash Prices and Government Programs in Acreage Response', *Western Journal of Agricultural Economics*, Vol. 8, No. 1, pp.27–33.

GCES (Georgia Cooperative Extension Service), 1992, *Crop Enterprise Cost Analysis: South Georgia 1993*, AAE/AES /UGA, Athens, Georgia, October.

GCES (Georgia Cooperative Extension Service), 1992, *1992 USDA Demonstration Project Annual Report: Gum Creek Water Quality Project*, CES/UGA.

Hook, J.E., 1991, *Water Withdrawals for Irrigation in Drought Years*, ERC 03-91, The Coastal Plain Experiment Station, The University of Georgia, Tifton, Georgia.

Knisel, W.G., Davis, F.M. and Leonard, R.A., 1992, *GLEAMS Version 2.0: User Manual*, Southeast Watershed Research Laboratory/ARS/ USDA, Tifton, Georgia.

Knisel, W.G., Leonard, R.A., Davis, F.M. and Sheridan, J.M., 1991, 'Water Balance Components in the Georgia Coastal Plain: A GLEAMS Model Validation and Simulation', *Journal of Soil and Water Conservation*, Vol. 46, No. 6, pp.450–6.

Ritchie, J., Singh, U., Godwin, D. and Hunt, L., 1992, *A User's Guide to CERES Maize-V2.10*, 2nd edition, International Fertilizer Development Center, Muscle Shoals, Alaska.

Romero, C. and Rehman, T., 1989, *Multiple Criteria Analysis for Agricultural Decisions*, Series title: Developments in Agricultural Economics, Elsevier, Amsterdam.

Rosato, P. and Stellin, G., 1993, 'A Multi-criteria Approach to Territorial Management: The Case of the Carole and Bibione Langoon Nature Park', *Agricultural Systems*, Vol. 41, No. 3, pp.399–417.

Steuer, R.E., 1986, *Multiple Criteria Optimization: Theory, Computation, and Application*, John Wiley & Sons, Inc., New York.

Steuer, R.E., 1992, *Manual for the ADBASE: Multiple Objective Linear Programming Package*, Department of Management Science & Information Technology, The University of Georgia, Athens, Georgia.

Thomas, D.L., Smith, M.C., Leonard, R.A. and deSilva, F.J.K., 1990, 'Simulated Effects of Rapeseed Production Alternatives on Pollution Potential in the Georgia Coastal Plain', *Journal of Soil and Water Conservation*, Vol. 45, No. 1.

DISCUSSION OPENING — Slim Zekri *(University of Tunis)*

The paper tackles a serious environmental problem related to intensive agriculture. Farmers seek to maintain their revenue while the community looks for a reduction of the environmental burden which results from nitrate pollution. The multi-objective methodology is well suited to this type of issue where a conflict exists between the farmers and the community interests. Additionally, the authors are innovative in the sense that they consider four techniques: simulation models; multi-objective programming, willingness to participate in a cost sharing programme and econometric modelling. Nevertheless, it seems that the econometrically estimated Expected Net Return function lacks sense. In fact, a single farmer can either adopt a new Best Management Practice, use the current management practice or a combination of both. Thus the Expected Net Return cannot be the sum of the expectations of the net returns for both of the management practices. As presented, the Expected Net Return function could perhaps represent the community utility function of Gum Creek Watershed. But in such a case it does not represent the farmer's utility. With respect to the empirical data, I think that the case has been extremely simplified since only two crops are considered while a diversity of crops are grown on the farm. In the same way, peanuts and corn were thought to be non-irrigated. Irrigation is a major factor contributing to nitrogen leachate. Risk due to heavy rainfall events has not been taken into account. With respect to results, the figures in column 3 of table 4 differ from those presented in column 6 of Table 1. It would be useful to explain such differences.