Journal of Rural Development 17(1994) : 117-135

AN ANALYTICAL FRAMEWORK ASSESSING AGRICULTURAL POLLUTION CONTROL POLICY OPTIONS

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I. Introduction

Agricultural production processes generate pollution, such as pesticide and nutrient residuals, which may contaminate both ground water and surface water. In recent years, public concern over possible adverse effects of water pollution on both human health and the environment has been growing. Agricultural pollution control measures may be needed to maintain or improve water quality.

Baumol and Oates provide an extensive theoretical discussion of point-source pollution problems utilizing general equilibrium models. Their analysis implies the standard Pigouvian result which requires a tax per unit of pollution generating activity equal to its marginal external damage. Griffin and Bromley, assuming that it is either impossible or too costly to determine consumers' valuations of benefits from reducing pollutant emissions, develop a nonpoint externality theory. They reformulate Baumol and Oates' general equilibrium models into a classical optimization framework (optimization only with equality constraints) and identify four types of nonpoint-source pollution regulating policies: *nonpoint incentives, nonpoint standards, management practice incentives*, and *management practice standards*. This analytical framework has been adopted in many studies (e.g. Shortle and Dunn; Knapp et al.). Not many agricultural pollution

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control studies consider more than one pollutant, even though charges or standards should be imposed on all sources of pollution which reduce environmental quality. If different pollutants can be assumed to be perfect substitutes, or if only one source of pollution is problematic in the study area, then dealing with a single index of pollution can be justified. However, the assumption of perfect substitution between different pollutants may not be reasonable because there are many sources of pollution that have quite different physical, chemical, and/or biological effects on natural resources. In addition, a policy restricting a particular pollution source may induce an increase in another source of pollution currently not problematic up to a level exceeding the maximum allowable level. Hence, the analytical framework dealing with a single source of pollution needs to be expanded to incorporate as many pollution sources as possible without introducing nonessential detail or complexity.

The objectives of this paper are (1) to present a mathematical programming framework for economic analysis of pollution control policies dealing with multiple sources of pollution; and (2) to apply the analytical framework to a typical farm situation in the study area, and determine appropriate agricultural pollution control policies.

II. Analytical Framework

Let $\mathbb{x} = (x_1, \ldots, x_n)'$, $\mathbb{x} \in \Omega \subset R^n$, be a vector of inputs to the farm production process, $\mathbb{F}[(f_1(\mathbb{x}), \ldots, f_m(\mathbb{x}))']$ be a vector of crop production, $\mathbb{G}[(g_1(\mathbb{x}), \ldots, g_h(\mathbb{x}))']$ be a vector function of pollution production as a set of functions of inputs, and $\mathbb{z} = (z_1, \ldots, z_h)'$ be a vector of limits on total emissions imposed at the farm level. Suppose that all functions above are deterministic and known by the farmer as well as the regulatory agency. Assume further that the objective of the farm is maximization of net returns over fixed costs subject to the resource endowments and emission limits. Then a mathematical representation of the farm problem is

$$\begin{aligned} &\text{maximize}(\mathbb{x}): && \pi(\mathbb{x}) = \mathbb{p}'\mathbb{F}(\mathbb{x}) - \mathbb{w}'\mathbb{x} \\ &\text{subject to:} && \mathbb{G}(\mathbb{x}) \leq \mathbb{z} \\ & && \mathbb{x} \in \Omega \end{aligned} \tag{1}$$

where $\mathbf{F}:R^n \rightarrow R^m$, $\mathbf{G}:R^n \rightarrow R^h$, and Ω denotes a set constraint on input availability, $\mathbf{p}$ is an m*1 vector of crop prices, and $\mathbf{w}$ is an n*1 vector of input prices.

Suppose $\mathbf{x}^o$ is a local maximum solution to the nonlinear programming problem (1). If the feasible region is a convex set, and if the objective function is differentiable and concave over the feasible region, then $\mathbf{x}^o$ is a global maximum solution by the Kuhn-Tucker sufficiency theorem (Kuhn and Tucker). In addition, if $\mathbf{x}^o$ satisfies Kuhn-Tucker conditions and the objective function is differentiable and concave over the feasible region, and if every constraint function ($z_. - g_.(\mathbf{x})$) is differentiable and quasiconcave over the feasible region, then $\mathbf{x}^o$ is a global maximum solution by the Arrow-Enthoven sufficiency theorem (Arrow and Enthoven). However, some component functions of the vector function $\mathbf{G}$ which represent effluent production functions may be neither quasiconcave nor quasiconvex over Ω. For example, a lack of synchronization between soil nitrogen availability and crop nitrogen requirement caused by disproportionate use of irrigation water and nitrogen fertilizer leads to more nitrate losses even with reduced levels of both inputs. In this case, there is no guarantee of obtaining a true global optimum solution for the problem.

However, linear programming (LP) provides an acceptable framework for solving the problem involving multiple pollution sources. A reformulation of the problem (1) in a LP framework is

$$\begin{aligned} \text{maximize}(\mathbf{x}): \quad & \pi(\mathbf{x}) = \mathbf{p}'\mathbf{F}\mathbf{x} - \mathbf{w}'\mathbf{x} \\ \text{subject to:} \quad & \mathbf{A}\mathbf{x} \leq \mathbf{b} \\ & \mathbf{G}\mathbf{x} \leq \mathbf{z} \\ & \mathbf{x} \geq \mathbf{0} \end{aligned} \tag{2}$$

where $\mathbf{x}$ is an n*1 vector of farm production activity levels; $\mathbf{F}$ is an m*n coefficient matrix representing relationships between farming activities and output; $\mathbf{A}$ is an k*n technical coefficient matrix; $\mathbf{b}$ is an k*1 vector of RHS values; $\mathbf{G}$ is an h*n coefficient matrix representing relationships between farming activities and generations of emissions; $\mathbf{z}$ is an h*1 vector of emission limits; $\mathbf{p}$ is an m*1 vector of product prices; and $\mathbf{w}$ is an n*1 vector of unit costs for activities. Suppose $\mathbf{b}_2$ and $\mathbf{z}_2$ are vectors of binding constraints. Then, the Lagrangian to problem (2) is

$$L(\mathbf{x}, \lambda_2, \mu_2; \mathbf{p},\mathbf{w},\mathbf{b}_2,\mathbf{z}_2) = \mathbf{p}'\mathbf{F}\mathbf{x} - \mathbf{w}'\mathbf{x} + \lambda_2'(\mathbf{b}_2-\mathbf{A}_2\mathbf{x}) + \mu_2'[\mathbf{z}_2-\mathbf{G}_2\mathbf{x}] \quad (3)$$

If the parameters to the problem are assumed to be fixed at ($\mathbf{p}^o$, $\mathbf{w}^o$, $\mathbf{b}_2^o$, $\mathbf{z}_2^o$), then, by the implicit function theorem, there exist choice functions $X(\mathbf{p}, \mathbf{w}, \mathbf{b}_2, \mathbf{z}_2)$, $\lambda_2(\mathbf{p}, w, \mathbf{b}_2, \mathbf{z}_2)$, and $\mu_2(\mathbf{p}, \mathbf{w}, \mathbf{b}_2, \mathbf{z}_2)$ such that $\mathbf{x}^* = X(\mathbf{p}, \mathbf{w}, \mathbf{b}_2, \mathbf{z}_2)$, $\lambda_2^* = \lambda_2(\mathbf{p}, \mathbf{w}, \mathbf{b}_2, \mathbf{z}_2)$, and $\mu_2^* = \mu_2(\mathbf{p}, \mathbf{w}, \mathbf{b}_2, \mathbf{z}_2)$ that solve the first-order conditions for the optimization of (3) for all ($\mathbf{p}, \mathbf{w}, \mathbf{b}_2, \mathbf{z}_2$) in some open neighborhood of ($\mathbf{p}^o$, $\mathbf{w}^o$, $\mathbf{b}_2^o$, $\mathbf{z}_2^o$). Therefore, once a set of upper limits on total emissions ($\mathbf{z}$) is determined, four distinct pollution control policy parameters are determined accordingly.

The vector of binding emission limits ($\mathbf{z}_2^*$) conforming to the optimum solution represents *nonpoint standards*. The vector of shadow prices (μ_2^*) of binding emission limits represents *nonpoint incentives*. The optimum activity levels ($\mathbf{x}^*$) represents *management practice standards*. In other words, the LP solution to the problem is the least-cost rearrangement of production activities to comply with given environmental policy goals. The emission limits ($\mathbf{z}$) would be attained by imposing μ_2^* as effluent taxes to either every unit of pollution sources or extra pollution over the limits ($\mathbf{z}$). These two alternative ways of imposing effluent tax are equally efficient in an economic sense, but have quite different equity implications. Effluent taxes charged to every unit of pollution ($\mu_2^{*\prime}\mathbb{G}_2\mathbf{x}^*$) would significantly decrease net returns to the farm relative to effluent taxes charged to the excess pollution over the limits [$\mu_2^{*}(\mathbb{G}_2\mathbf{x}^* - \mathbf{z}_2^*)$], even though the resultant emission levels for both cases would be exactly same if the farmer is rational. *Management practice incentives* use $\mu_2^{*\prime}\mathbb{G}_2$ as a vector of charges to corresponding activity levels undertaken by the farmer. The total amount of *management practice incentives* also would be $\mu_2^{*\prime}\mathbb{G}_2 x^*$ since the rational farmer would adopt the optimal production activities ($\mathbf{x}^*$). Consequently, all the four policy tools induce the least-cost rearrangement of production activities to comply with the given policy goal. In this sense, the four policies are equally efficient, even though administration costs may be different. The decrease in net returns to the farmer can be compensated through lump-sum payments without losing economic efficiency.

Monitoring emissions from agriculture is extremely difficult since most cases of water pollution from agriculture appertain to nonpoint source pollution that cannot be traced to a specific spot. However, monitoring emissions is not necessary to implement the four policy tools in the above framework. If the linkage between production activities and pollution generation is explicitly included in the analysis, emission levels can be estimated when production activities are known. The use of a crop growth/chemical movements simulation model known as EPIC-PST (Sabbagh et al.) provides technical data showing the linkage for this analysis.

III. Application of Analytical Framework

1. Crop Production Activities and Rotation Modeling

Four crops (wheat, peanuts, cotton, grain sorghum) which dominate crop production in Southcentral Oklahoma are included in the analysis. Benefits which accrue from peanuts and cotton rotations are well documented in the literature. Peanuts are quite susceptible to attack by nematodes and soil-borne diseases, and should be rotated with other crops such as small grain or grain sorghum that are not susceptible to the same pathogens (Woodroof). Cotton rotations with grain sorghum, small grain, or legumes decrease the incidence and severity of diseases and weed problems (Bell, Chandler). The importance of peanuts and cotton rotations requires adequate modeling of multi-year crop rotations. In addition, the model should allow flexibility in choosing input use levels associated with each rotation system and free adjustment in response to pollution control policy restrictions.

Suppose that the yield of a crop depends on the crops grown on the same soil in the previous two years. Also suppose that nitrogen and irrigation water application levels of the previous years do not affect yield the following year because the soil looses residual nitrogen through runoff or percolation below the crop root zone and recovers the moisture level during the period following harvest. Consider the rotation system peanuts(P)-cotton(C)-grain sorghum(G) with high(H), medium(M), and low(L) input levels. Table 1 illustrates the basic structure of the rotation model. Rotational

TABLE 1 Simplified Rotation Model

RHS	PCGH	PCGM	PCGL	CGPH	CGPM	CGPL	GPCH	GPCM	GPCL
PC	1	1	1				-1	-1	-1
CG	-1	-1	-1	1	1	1			
GP				-1	-1	-1	1	1	1
LAND	1	1	1	1	1	1	1	1	1

linkages represented by 1 or -1 indicate that PCG (sorghum after cotton after peanuts) uses PC and supplies CG, CGP (peanuts after sorghum after cotton) uses CG and supplies GP, and GPC (cotton after peanuts after sorghum) uses GP and supplies PC. These three seemingly different cropping sequences are actually the same rotation if repeated. Notice that each crop production activity uses only one unit of land and produce only one crop (e.g.PCG produces only grain sorghum).

Suppose that 120 acres of a three-year rotation, Peanuts(M)-Cotton(H)-Grain sorghum(L), is the optimum solution. Then the model will choose 40 acres of CGPM, 40 acres of GPCH, and 40 acres of PCGL simultaneously since they are constrained by rotational linkages. Meanwhile, continuous cropping systems do not require rotational linkages since they use and supply the same rotational constraints (e.g. CCC uses CC and supplies CC). This modeling approach reduces the number of activities significantly. We use nine different input levels for each cropping system in the empirical analysis. In this case, the number of activities representing only one 3-year rotation system in terms of explicit crop sequences would be 9*9*9 while the above modeling approach requires 9*3 activities. Furthermore, this model has the advantages of El-Nazer and McCarl's modeling approach in that it determines freely the optimal long-run rotation.

2. Farm Situation

Using data from the 1987 Census of Agriculture-County Data, the Soil Survey of Caddo County, and personal interviews with the County Extension Agent (Beerwinkle), a hypothetical farm was developed for Caddo County, Oklahoma. The hypothetical farm is comprised of 120 acres of Cobb fine sandy loam soil, 120 acres of Grant loam soil, 150 acres of Pond Creek fine sandy loam soil, and 90 acres of Port silt loam soil with 3 percent slopes. A total of 260 acres are irrigated using high pressure center pivot systems with an average application efficiency of 75 percent and 150 feet of pumping lift. The farm has a peanut quota of 3,000 cwt and a 100-acres wheat base with a base yield of 35 bushels per acre. A 5 percent set-aside and 15 percent normal flex acreage rule are assumed for the wheat program. The area average of input and output prices for the 1991 crop year are used in the analysis.

3. Simulation of Crop Growth/Chemical Movements

For the simulation of crop growth and soil and chemical movements, EPIC-PST (Sabbagh et al.) is used. EPIC-PST combines the EPIC (Erosion Productivity Impact Calculator) model (Williams et al.) with the pesticide subroutines of the GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) model (Leonard et al.). The resulting model can simulate simultaneously the effects of different agricultural management practices in a specific soil on crop yield, as well as nutrient and pesticide losses by surface runoff, sediment movement and leaching below the soil profile. Simulated crop yields for the soils and production practices under both irrigated and dryland conditions in Caddo County match the yield experiences by farm operators in the area reasonably well. Ability of EPIC-PST to simulate chemical movements has been validated by comparing with observed data from Baton Rouge, LA, and Tifton, GA(Sabbagh et al., Mapp et al.). Field data on chemical movements do not exist for our study area, so field validation of that component of the model was not possible. Nevertheless, we predicted chemical movements using EPIC-PST and based our analysis on those predictions.

We identified the most common tillage practices and pesticides used by study area producers of each crop under dryland and irrigated conditions. In addition, we determined 9 different input use levels for each cropping system - 3 irrigation levels and 3 different nitrogen application levels for each irrigation level. For example, HL stands for high irrigation and low nitrogen application, MH stands for medium irrigation and high nitrogen application, LH stands for no irrigation and high nitrogen application, and so on. HH, MH, and LH use nitrogen levels which approximately equate marginal value product and marginal factor cost of nitrogen fertilizer with respect to each irrigation level, given the relative prices used in this study. Except for peanuts, the differences of nitrogen use between high and subsequent levels are 15-20 pounds per acre under irrigated condition, and 10 pounds per acre for dryland. Phosphorous, potassium, and micronutrient application levels are assumed to be fixed.

For each cropping system, soil, irrigation level, and nitrogen level, a 28-year EPIC-PST simulation run was conducted using daily weather data for the study area. EPIC-PST generates a 28-year distribution of crop yields, soil erosion with runoff (USLE), nitrate loss with runoff (YNO3), mineral nitrogen loss with percolation (PRKN), pesticide (active ingredient) loss with runoff and sediment, and pesticide (active ingredient) loss with percolation for each soil-management strategy combination. The potential of pesticide losses to surface and ground water from each activity are aggregated into a single index number using a method similar to that developed by Hoag and Hornsby. The surface water hazard index (I_S) and the ground water hazard index (I_g) are calculated as

$$I_S = \frac{\text{pesticide losses with runoff and sediment}}{\text{Lethal Concentration 50}}$$

$$I_g = \frac{\text{pesticide losses with percolation * 100}}{\text{Lifetime Health Advisory Level (Equivalent)}}$$

The Lifetime Health Advisory Level or Equivalent is defined by USEPA as the concentration of a chemical in drinking water that is not expected to cause any adverse health effects over a lifetime exposure with a margin of safety. Lethal Concentration 50 is the concentration of a chemical at which 50% of the test fish species die. In the analysis, we use average measures of the 28-year distribution of soil erosion with runoff (USLE), nitrogen movements (YNO3, PRKN), and pesticide movements (I_s, I_g). Among them, USLE, YNO3, and I_s are perceived as the potential of surface water contamination, while PRKN and I_g are perceived as the potential of ground water contamination.

To convert EPIC-PST output into the coefficient matrix of the mathematical programming model, several programs written in PASCAL language were used. For the calculation of operating cost, the Expanded Budget Generator developed by Norris is used. A simplified model structure is presented in Table 2. The model contains 1,650 activities and 100 constraints.

IV. Selected Results

1. Baseline Results

Baseline results in Table 3 reflect the current production situation without any form of agricultural pollution control policy. A 3-year Peanuts(HL or HM)-Cotton(HH)-Sorghum(LH) rotation occupies 57. 5 percent of the farm acreage. A 3-year rotation of Cotton(HH)-Cotton(HH)-Sorghum(LH) is grown on 23.8 percent of the farm acreage. Program wheat is grown on the rest of the farm. Both peanuts and cotton are grown under the high irrigation level, but grain sorghum and wheat are grown under dryland conditions because of the constraint on irrigated acres. Peanuts use the low nitrogen level since peanuts require only a small amount of nitrogen as starter fertilizer. All other crops use the high nitrogen level.

Total amounts of chemical movements also are presented in Table 3. These indicate that soil erosion with runoff exceeds the boundary of highly erodible land (8.0 ton per acre), and that amounts of nitrogen and pesticide movements in runoff and percolation through the plant root zone are substantial. Defining the potential of water contamination caused by the amounts of soil and chemical movements is beyond the scope of this study. Nevertheless, based on the baseline results, various policy scenarios and pollution abatement

TABLE 2 Simplified Tableau of Mathematical Programming Model

	Produc -tion	Crop Sale	Water Pumping	Nitrogen Purchase	Pesticide Purchase	Soil/Chemical Movements	RHS
Objective Function	-A	B	-C	-D	-1	0 or - μ_2^*	
Rotational Linkages	1 or 0						
Soil Acreage Constraints	1						I
Irrigated Land Constraints	1 or -1						J
Crop Production Accounting Rows	-E	1					
Water Pumping Accounting Row	W		-1				
Nitrogen Application Accounting Row	F			-1			
Pesticide Cost Accounting Row	G				-1		
Soil/Chemical Movements Accounting Rows	H					-1	
Water Pumping Constraint			1				K
N Application Constraint				1			L
Soil/Chemical Movements Constraints						1	M

TABLE 3 Summary of Baseline Results

Optimum Cropping System

Cobb fine sandy loam soil
Cotton(HH)-Cotton(HH)-Sorghum(LH): 114 acres
Program Wheat(LH): 6 acres

Grant loam soil
Peanuts(HM)-Cotton(HH)-Sorghum(LH): 36 acres
Program Wheat(LH): 84 acres

Pond Creek fine sandy loam soil
Peanuts(HL)-Cotton(HH)-Sorghum(LH): 150 acres

Port silt loam soil
Peanuts(HL)-Cotton(HH)-Sorghum(LH): 90 acres

Soil and Chemical Losses

USLE: 4,365 ton (9.1 ton per acre)
YNO3: 1,852 Kg (8.5 pounds per acre)
PRKN: 221.6 Kg (1.0 pound per acre)
Is: 343,750
Ig: 2,836

Returns above total operating costs: $92,632 ($193/acre)

goals can be established to evaluate potential economic and environmental quality impacts of the policy options. To illustrate the application of the analytical framework, the model was solved for several pollution control scenarios. Each policy option can be assessed through comparison of results to the baseline results.

2. Scenario I: 100 Percent Surtax on Nitrogen and Pesticide Use

Charging a surtax on pollution generating-inputs is often discussed as a feasible pollution control policy. Because the differences in profitability among activities reflected in the model are relatively uniform across production activities even with a 100 percent surtax imposed on both nitrogen and pesticides, this policy option has little impact on use of these inputs, cropping pattern, or water quality. The primary impact of this scenario is to reduce net returns to the farm by 36 percent relative to the baseline solution.

3. Scenario II: 50 Percent Abatement of I_g from Baseline

This policy goal is an example of the *nonpoint standards.* It specify the maximum level of Ig the farm may generate without penalty. The *nonpoint incentive* is the shadow price of the water quality constraint (the upper limit of Ig). In this sense, *nonpoint standards* and *nonpoint incentives* are the dual of each other. The optimum *nonpoint incentive* under this scenario turns out to be $0.007. It can be imposed on either every unit of Ig or on extra units of Ig over the limit as an effluent tax. Under this scenario, the method of charging the effluent tax (*nonpoint incentives*) has little impacts on net returns to the farm since the tax rate is infinitesimal.

The optimum production activity levels represent the *management practice standards* (see Table 4), and are interpreted as the actual farm production activity levels specified by the regulatory agent. In other words, the farmer is forced to adopt the activity levels since they are the most efficient way to achieve the water quality goal. The *management practice incentives* are taxes imposed on the activity vector adopted by the farmer ($\mu_2^{*\prime}\mathbb{G}_2\mathbb{X}$, where μ_2^* = $0.007, $\mathbb{G}_2$ is a 1*n vector in this case). A rational farmer would adopt the same activity levels as the management practice standards ($\mathbb{X}^*$). Hence, the four policy parameters are equally efficient. These explanations of the four policy options apply also to the following scenarios.

The reduction in Ig can be attained by substituting cropping activities with lower Ig for those with higher Ig; e.g., simply by moving 58 acres of Cotton(HH)-Cotton(HH)-Sorghum(LH) from Cobb fine sandy loam soil to Grant loam soil and 58 acres of program wheat(LH) from Grant loam soil to Cobb fine sandy loam soil. The decrease in net returns is less than 1 percent. Changes in soil erosion and other chemical movements relative to baseline results are not significant under this scenario (see Figure 1).

4. Scenario III: 50 Percent Abatement of PRKN from Baseline

The policy goal represents the *nonpoint standard.* The *nonpoint*

TABLE 4. Results for Scenario II

Nonpoint Incentives

YNO3: \$0.00/kg	PRKN: \$0.00/kg
I_S: \$0.00/unit	I_g: \$0.007/unit

Management Practice Standards

Cobb fine sandy loam soil
- Cotton(HH)-Cotton(HH)-Sorghum(LH): 56 acres
- Program Wheat(LH): 64 acres

Grant loam soil
- Peanuts(HL)-Cotton(HH)-Sorghum(LH): 36 acres
- Program Wheat(LH): 26 acres
- Cotton(HH)-Cotton(HH)-Sorghum(LH): 58 acres

Pond Creek fine sandy loam soil
- Peanuts(HL)-Cotton(HH)-Sorghum(LH): 150 acres

Port silt loam soil
- Peanuts(HL)-Cotton(HH)-Sorghum(LH): 90 acres

Returns above total operating costs: \$92,622 (\$92,612)

incentive is \$29.08 per kilogram of PRKN. The *management practice standards* are presented in Table 5. These represent the least-cost rearrangement of production activities to comply with the policy goal of abating 50 percent of PRKN from the baseline. The reduction in PRKN is achieved mainly by replacing the high nitrogen level with the low nitrogen level. If either the *nonpoint incentive* or *management practice incentive* is applied to every unit of PRKN, then net returns would be reduced to \$88,163. Notice that this policy scenario induces a 48 percent increase in the amount of Ig (see Figure 1). The shift of the rotation system Peanuts-Cotton-Sorghum to Cobb fine sandy loam soil appears to be responsible for the significant increase in Ig since both the rotation system and the soil have high pesticide-leaching potential. This result suggests the need of a pollution control policy that restricts all sources of pollution simultaneously.

TABLE 5 Results for Scenario III

Nonpoint Incentives

YNO3: \$0.00/kg	PRKN: \$29.08/kg
I_s: \$0.00/unit	I_g: \$0.00/unit

Management Practice Standards

Cobb fine sandy loam soil
- Peanuts(HL)-Cotton(HH)-Sorghum(LM): 103 acres
- Cotton(HH)-Cotton(HH)-Sorghum(LM): 17 acres

Grant loam soil
- Peanuts(HL)-Cotton(HH)-Sorghum(LL): 106 acres
- Peanuts(HL)-Cotton(HM)-Sorghum(LL): 14 acres

Pond Creek fine sandy loam soil
- Peanuts(HL)-Cotton(HH)-Sorghum(LL): 60 acres
- Program Wheat(LH): 90 acres

Port silt loam soil
- Cotton(HH)-Cotton(HH)-Sorghum(LM): 90 acres

Returns above total operating costs: \$91,385 (\$88,163)

5. Scenario IV(V): 25(50) Percent Abatement of YNO3, PRKN, I_s, and I_g

Again, the *nonpoint standards* are the scenarios themselves. The *nonpoint incentives* and the *management practice standards* for these scenarios are presented in Table 6 and Table 7. If either the *nonpoint incentives* or *management practice incentives* are imposed on every unit of YNO3, PRKN,I_s, and I_g, then net returns to the farm would be reduced to the values in parentheses. A mathematical representation of the difference between the two values is $\mu_2^{*\prime}\mathbf{z}_2^*$. If one of the two incentives is imposed on the excess emission levels over *nonpoint standards*, then the farmer actually pays no tax. It is because the rational farmer would adopt $\mathbf{x}^*$, and then, $\mathbb{G}_2\mathbf{x}^*$ equals $\mathbf{z}_2^*$. Comparison of *management practice standards* in Table 6 and Table 7 indicates that stricter water quality goals can be attained by changing

TABLE 6 Results for Scenario IV

Nonpoint Incentives

YNO3: \$9.02/kg	PRKN: \$0.00/kg
Is: \$0.050/unit	Ig: \$0.00/unit

Management Practice Standards

Cobb fine sandy loam soil
- Peanuts(LL)-Cotton(LH)-Sorghum(LM): 73 acres
- Program Wheat(LH): 47 acres

Grant loam soil
- Peanuts(HL)-Cotton(MH)-Sorghum(LL): 67 acres
- Program Wheat(LH): 53 acres

Pond Creek fine sandy loam soil
- Peanuts(HL)-Cotton(HH)-Sorghum(LM): 83 acres
- Peanuts(HL)-Cotton(HM)-Sorghum(LM): 67 acres

Port silt loam soil
- Peanuts(HL)-Cotton(HH)-Sorghum(LH): 24 acres
- Cotton(HH)-Cotton(HM)-Sorghum(LH): 66 acres

Returns above total operating costs: \$85,595 (\$60,176)

TABLE 7 Results for Scenario V

Nonpoint Incentives

YNO3: \$9.54/kg	PRKN: \$18.81/kg
Is: \$0.059/unit	Ig: \$0.00/unit

Management Practice Standards

Cobb fine sandy loam soil
- Peanuts(LL)-Cotton(LH)-Sorghum(LM): 120 acres

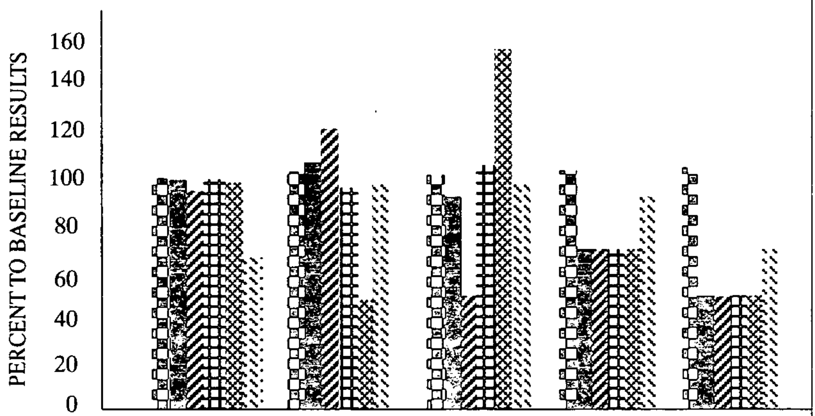
Grant loam soil
- Peanuts(HL)-Cotton(LM)-Sorghum(LL): 8 acres
- Peanuts(LL)-Wheat(LL)/Sorghum(LL)-Cotton(LM): 12 acres
- Program Wheat(LH): 100 acres

Pond Creek fine sandy loam soil
- Peanuts(HL)-Cotton(LH)-Sorghum(LL): 140 acres
- Peanuts(HL)-Cotton(HM)-Sorghum(LL): 10 acres

Port silt loam soil
- Peanuts(HL)-Cotton(HM)-Sorghum(LL): 51 acres
- Cotton(HH)-Cotton(HH)-Sorghum(LH): 18 acres
- Cotton(HM)-Cotton(HL)-Sorghum(LH): 21 acres

Returns above total operating costs: \$76,337 (\$55,280) management practices from high input use levels to medium or low input use levels without major changes in overall cropping systems. However, underutilization of agricultural inputs incur substantial economic losses to the farm.

Figure 1 Economic & Environmental Impacts of Various Policy Options



	SCENARIO Ⅰ	SCENARIO Ⅱ	SCENARIO Ⅲ	SCENARIO Ⅳ	SCENARIO Ⅴ
USLE	100	104	105	106	107
YNO3	100	107	91	75	50
PRKN	96	121	50	75	50
Is	100	95	109	75	50
Ig	100	50	148	17	26
NET RETURNS	64	100	99	92	82

USLE YNO3 PRKN
Is Ig NET RETURNS

V. Summary and Conclusions

There are many sources of agricultural pollution that have quite different physical, chemical, and/or biological effects on the environment. A pollution control policy restricting only a particular pollution source may induce increases in other sources of pollution. Hence, agricultural pollution control measures should consider all pollution sources simultaneously. The development of simulation models such as EPIC-PST has provided linkages between production activities and generation of various sources of water pollution. This paper presents an analytical framework and a modeling procedure that uses information provided by EPIC-PST simulation runs and a mathematical programming model to assess agricultural pollution control policy alternatives for multiple crops, soils, rotations, and agricultural pollution sources.

Model results indicate (1) a substantial surtax imposed on agricultural chemicals may not be an efficient agricultural pollution control policy alternative; (2) a typical Caddo County farm with multiple soil types can attain a policy goal restricting a single source of pollution without substantial economic loss, but other sources of pollution may increase; (3) the policy goal restricting most sources of agricultural pollution can be achieved by reducing irrigation and nitrogen applications without significant changes in overall cropping pattern, but with substantial economic losses.

The empirical analysis in this study is confined to a individual farm. However, the analytical framework and modeling approach presented in this paper can be readily extended to a regional analysis.

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