ESTIMATION OF ECONOMIC AND ENVIRONMENTAL TRADEOFFS FOR ALTERNATIVE FARMING SYSTEMS

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Tony Prato, Feng Xu and J.C. Ma[1]

Abstract

THIS STUDY PROPOSES AN EMPIRICAL METHOD FOR ESTIMATING ECONOMIC AND ENVIRONMENTAL TRADEOFFS. ECONOMIC AND ENVIRONMENTAL TRADEOFF FRONTIERS ARE ESTIMATED USING DATA GENERATED FROM A MULTIOBJECTIVE PROGRAMMING MODEL FOR A CASE STUDY FARM IN MISSOURI. RESULTS INDICATE THAT TRADEOFFS EXIST BETWEEN ECONOMIC AND ENVIRONMENTAL OBJECTIVES AND BETWEEN TWO SELECTED ENVIRONMENTAL OBJECTIVES. THEREFORE, IT IS NECESSARY TO ACCOUNT FOR ALL RELEVANT ECONOMIC AND ENVIRONMENTAL EFFECTS OF FARMING SYSTEMS IN FARMING SYSTEM EVALUATIONS.

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INTRODUCTION

To prescribe recommendations for economically and ecologically sustainable agricultural production systems, both economic and ecological effects of agricultural production systems and their relationships need to be understood. Microeconomic level analysis is necessary to understand such economic-ecological relationships at various aggregation levels. The goals for sustainable development are environmental integrity, economic efficiency, and equity including present and future generations and cultural issues (Young 1992). The integration of natural resources into the framework of economic theory is a prerequisite for environmental policy (Opschoor and Straaten 1993). Sustainability is intimately connected with the issue of justice, rights and obligations. Moral and ethical constraints to a policy prescription must always be recognized and acknowledged. Inter-generational equity considerations are more easily met for individuals and communities who believe that while they have a right to consume existing resources, they also have an obligation to act as stewards for future generations.

Nonpoint source pollution from agriculture is a major contributor to water contamination. An increasing concern is the economic and environmental consequences of soil erosion and nitrate leaching. Both soil erosion and nitrate leaching have received much attention due to losses in productivity, sedimentation associated with soil erosion and health risks associated with nitrate leaching to groundwater. Few studies have explicitly accounted for economic and environmental tradeoffs in evaluating farming systems.

It is often difficult to identify a single social preference criterion relating to agricultural and environmental policies because the decision making process is influenced by multiple competing objectives. Agricultural producers are mainly concerned about farm profitability while conservationists and environmentalists emphasize resource conservation. Economic and environmental objectives are oftentimes competitive and noncommensurable, especially in the short term when technology is fixed (Haimes et al. 1975, 1990). In order to improve the choice of farming systems, explicit recognition should be given to economic and environmental tradeoffs for different farming systems. An improvement in one environmental objective such as reduction in soil erosion can adversely affect another environmental objective such as reduction in nitrate leaching (Kim and Mapp 1993). These tradeoffs may not be uniform throughout the meaningful ranges of the environmental objectives. A farming system may be effective in reducing soil loss but may increase leaching of nitrate to groundwater. Furthermore, environmental quality may not be improved without decreasing farm income. This kind of tradeoff, which is implicit in other studies, will be explicitly evaluated in this study.

Agricultural policy analysis should consider multiple objectives including farm income, soil erosion, nitrate leaching and any other surface water quality indicators because all of these measures are interconnected. Although there is not necessarily a direct tradeoff between water quality and farm profitability for a proposed policy change (Contant et al. 1993), economic-environmental tradeoffs are common in agricultural production.

This paper evaluates what sustainable agricultural production should encompass and how sustainable agricultural production could be achieved at a microeconomic level. A case study is used to illustrate various issues in selecting a sustainable agricultural production system.

Due to the wide range of choices for economic and environmental objectives, this paper is limited to three objectives: farm income, soil erosion, and nitrate available for leaching. A relevant question to ask is: what are the efficient combinations of the three objectives? This paper first identifies the efficient combinations of these three objectives, then evaluates tradeoffs between net farm income and reduction in soil erosion, between net farm income and abatement of nitrate available for leaching, between reduction in soil erosion and abatement of nitrate available for leaching, and discusses relevant policy implications. A case study simulation approach is used to generate efficient combinations of the three objectives for six farming systems considered in Missouri's Management Systems Evaluation Area (MSEA) Project.

Specifically, multiobjective programming (MOP) and regression are used to determine and evaluate tradeoffs among multiple objectives. This study makes explicit the monetary equivalence of changes in two environmental indicators for a case study farm. Tradeoffs are examined between any two of three objectives: one economic objective "net return", and two environmental objectives "soil erosion" and "nitrate available for leaching" for a case study farm. Results are used to characterize an efficient set of three objectives and to derive various tradeoff information.

DESCRIPTION OF MODEL

A crop farmer uses land ($\mathbf{L}$) to produce agricultural products. The farmer chooses a farming system or set of farming systems ($\mathbf{x}$) from all available farming systems. Production under current technology brings the farmer economic profit and results in environmental effects such as soil erosion and chemical leaching. Without losing generality, these relationships can be characterized as follows:

$$\pi = \pi(\mathbf{x})$$

$$\rho = \rho(\mathbf{x})$$

$\ell = \ell(\mathbf{x})$

where π is economic profit, ρ is soil erosion, ℓ is chemical leaching, and $\mathbf{x}$ is a set of farming systems.

There are two major views regarding the sustainability of current agricultural production systems. One view is that the actual $\mathbf{x}$ used on a farm is not most efficient and that a Pareto-superior position can be obtained by changing from $\mathbf{x}$ to $\mathbf{x}'$ so that $(\pi' \quad \rho' \quad \ell') \succ (\pi \quad \rho \quad \ell)$, i.e., there exists an alternative farming system(s) that provides a preferred set of economic and ecological outputs. In other words, the farm can achieve higher economic profit without increasing soil erosion and chemical leaching, or soil erosion can be reduced without decreasing profit and increasing chemical leaching. This view is inconsistent with the neo-classical microeconomic theory for a rational farmer under usual assumptions of perfect competition. Several studies provide empirical results on this issue, namely Xu and Prato (1992) and Contant et al. (1993).

An alternative view is that the farmer achieves an optimum, i.e., $(\pi \quad \rho \quad \ell)$ is the best output mix possible. There does not exist any alternative farming system that results in a more preferred set of economic and ecological outputs relative to the current set. That is, $\nexists\, \mathbf{x}' : (\pi' \quad \rho' \quad \ell') \succ (\pi \quad \rho \quad \ell)$. Therefore, changes from $\mathbf{x}$ to $\mathbf{x}'$ would entail tradeoffs. Under current technology, the farm cannot achieve higher economic profit without increasing soil erosion and chemical leaching, nor could soil erosion be reduced without decreasing profit and increasing chemical leaching.

However, a new (or modified) Pareto-superior farming system $\mathbf{x}''$ can be found through research and development. Change from $\mathbf{x}$ to $\mathbf{x}''$ is superior because $\exists\, \mathbf{x}'' : (\pi'' \quad \rho'' \quad \ell'') \succ (\pi \quad \rho \quad \ell)$. This implies that a new and more preferred set of economic and ecological outputs is achieved with a new technology.

The problem still arises: society may regard both $(\pi \quad \rho \quad \ell)$ under the current technology and $(\pi'' \quad \rho'' \quad \ell'')$ under the new technology as unacceptable (or undesirable) because environmental impacts are too high and/or economic profit is too low. Therefore, society's preferred set of outcomes may be different from the efficient agricultural outcomes under either current technology or new technology. Consideration of interactions between society and an individual farmer is essential.

METHODS AND PROCEDURES

Tradeoffs between farm income and environmental effects of agricultural production can be represented in a two-dimensional economic-environmental space. Each point on EE' in Figure 1 represents efficient combinations of economic returns and soil erosion objectives for a given technology. This mapping is similar to that offered Carriker (1992) and by Olsen and Gowdy (1992). Points above EE' are not attainable. Points below EE' are inefficient. When erosion equals ρ , point A is not efficient because net return can be increased up to point B without increasing soil erosion. Similarly, when net return equals π , point C is not efficient because soil erosion can be reduced to point B without decreasing net return.

If a decision maker's preferences for net farm income and soil erosion are known, $\mu = \mu(\pi, \rho)$, the optimum combination of net return and soil erosion on EE' can be determined. The EE' frontier can also assist policy makers in designing incentive schemes to achieve economic and environmental objectives. Evaluation of incentive policies aimed at reducing environmental problems, such as effluent restrictions and effluent charges, can be evaluated with this framework. A per-unit charge on pollutants is commonly considered as an efficient method of internalizing external costs. Since effluent charges reduce farm income, they cause a farmer to change production in a manner that improves environmental quality. If the existing preferences and technologies are not ecologically sustainable, it is necessary either to regulate economic activity levels within the existing structure of preferences, or to change that structure of preferences, or both (Common and Perrings 1992). The appropriate instruments, whether price manipulation, education, or changes in property rights, will vary depending on institutional and other factors. An ecological economic approach places the requirements of the system above those of the individual. This involves ethical judgments about the role and rights of present and future generations (Pearce, 1987).

When another environmental indicator such as nitrate available for leaching is introduced, the two-dimensional frontier becomes a three-dimensional surface. All three objectives are inter-related. Levels of environmental criteria, such as safe minimum standards, critical loads and maximum contaminant levels, can be considered as proxies for the actual thresholds of unsustainability. Considering these thresholds together with the synergistic and antagonistic interdependencies between various environmental objectives helps to define an environmental utilization space, the surface of which is an environmental utilization possibilities frontier (Opschoor and Straaten 1993). This study estimates an efficient surface for the three objectives. This surface can be used to derive tradeoffs between any two objectives.

How is a farmer encouraged to move from point E' to point B on the tradeoff frontier EE'? A pure profit maximizing farmer would choose E', where net return is a maximum within the range of values for π and ρ under consideration. However, at E', ρ (and nitrate available for leaching, ℓ) is likely to be at its maximum level. If the farmer wants to reduce environmental loads by changing farming systems, s/he could achieve B or some other points on EE' depending on his/her preferences. For example, if the farmer is indifferent between (π, ρ, ℓ)=(100,000, 10, 15) and (80,000, 5, 10), then the farmer's utility is not changed by sacrificing $20,000 in income to achieve a 5 TAY reduction in soil erosion and a 5 lbs/acre reduction in nitrate available for leaching. In general, however, a farmer would move from E' to B only if an incentive payment of $20,000 is provided. This is often referred as compensation policy. An alternative policy is to impose an emission charge of $20,000 on the farm which can be used to offset the damages caused by excessive erosion and nitrate leaching. Evaluation of alternative policies is impossible without knowledge of the tradeoffs.

The MOP model as presented below assumes no *a priori* information about decision maker preferences. The primary purpose of the MOP model is to generate information about noninferior solutions. Noninferior solutions are a "set of feasible solutions such that no other feasible solutions can achieve the same or better performance for all objectives and strictly better for at least one objective." (Romero et al. p.78, 1987). There are numerous non-inferior solutions.

Let x be a vector of decision variables; $f_j(x), j = 1, \cdots, n$ be the jth objective function; and $g_i(x), i = 1, \cdots, m$ be the ith constraint. The feasible region is defined as $X = \{x | g_i(x) \leq 0, i = 1, \cdots, n\}$. An optimization problem is then formulated as

$$(1) \qquad \max_{x \in X} \left[f_1(x), \cdots, f_n(x)\right].$$

Point x^* is a noninferior solution if there exist no $x \in X$ such that $f_j(x) \geq f_j(x^*) \; \forall \; j$, and $f_j(x) > f_j(x^*)$ for at least one j. Noninferior solutions can be obtained by choosing one of the objective functions as the primary function to optimize and using the other functions as constraints. Haimes, et al. (1971, 1990 pp. 72-73) proved that the efficient set of noninferior solutions to the MOP is unique no matter which of the objective functions is optimized. That is, the efficient surface for the objective functions is identical regardless of which function is optimized.

In the MOP model used here, net farm return is maximized subject to average soil erosion rate, nitrate available for leaching, and other relevant constraints. Net farm income, average soil erosion rate and nitrate available for leaching change with respect to total acreage farmed and farming systems selected. The three-objective MOP model specified for this study is as follows:

(2) Maximize: $\pi(x) = \sum_i \sum_j \alpha_{ij} x_{ij}$

(3) subject to: $\rho(x) = \sum_i \sum_j \beta_{ij} x_{ij} \Big/ \sum_i \sum_j x_{ij} \le \rho^*$

(4) $\ell(x) = \sum_i \sum_j \gamma_{ij} x_{ij} \Big/ \sum_i \sum_j x_{ij} \le \ell^*$

(5) $\sum_i x_{ij} = S_j$

where x_{ij} is the acreage in farming system i and soil j. $\pi(x)$, $\rho(x)$ and $\ell(x)$ are the values of the three objective functions. Coefficients α, β, and γ are per acre net return, soil erosion rate and nitrate available for leaching, respectively. ρ^* and ℓ^* are the restrictions on soil erosion and nitrate available for leaching. Constraint (5) restricts acreage on each soil.[2] Labor is considered to be sufficient for the case study farm. Since an efficient surface (π, ρ, ℓ) is unique no matter which objective is optimized, there is no need to solve the problem by optimizing each objective to obtain the efficient and unique surface (π, ρ, ℓ). Solution procedures are outlined below.

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[2] To allow flexibility to change both acreage and farming systems, constraint (5) is relaxed to $\sum_i x_{ij} \le S_j$.

There are numerous noninferior solutions for an MOP model. Obtaining all noninferior solutions can be computationally expensive and even infeasible. If a subset of noninferior solutions can represent a "true" set of noninferior solutions reasonably well, this subset can be used to approximate (or predict) other noninferior solutions within a relevant range of objective values. Regression analysis can be used for prediction. Determining the number of noninferior solutions then becomes an empirical question. Only a subset of noninferior solutions are relevant for a particular decision maker. For example, a plausible "ideal" solution (a particular noninferior solution) is chosen as the starting point for a particular decision maker. Then other noninferior solutions close to the ideal solution are identified as the compromise solutions (Zeleny 1973; Romero 1987). The drawback of this approach is obvious. An "ideal" solution is difficult to identify *a priori*.

The model defined in (2)-(5) is first run without constraints (3) and (4) using an optimization software package such as GAMS (Brooke, et al. 1992). The resulting ρ and ℓ are defined as maximum *possible* values, which are denoted as (ρ_{max}, ℓ_{max}). When all acreage is farmed, the minimum *possible* values of ρ and ℓ are defined as $(\rho_{min}, \ell_{min}) = (\min[\beta_{ij}], \min[\gamma_{ij}])$. Interval $[\rho_{min}, \rho_{max}]$ is divided into m-1 equal subintervals and interval $[\ell_{min}, \ell_{max}]$ is divided into n-1 equal subintervals. Then the model is run $m \times n$ times using GAMS. Each run uses a particular combination of the values of ρ and ℓ. The resulting values of the three objectives and actual acreage in the solution are then used to estimate the efficient tradeoff surface. Note that actual binding values of ρ and ℓ are used rather than the ρ^* and ℓ^* values in constraints (3) and (4). A surface of three objectives as well as total acreage can be estimated as $F(\pi, \rho, \ell, L) = 0$. Acreage is a decision variable because it affects all three objectives.

DESCRIPTION OF DATA

Data is from a case study farm in central Missouri. The case study farm, study area and farming systems are briefly described. The case study farm is located in central Missouri. A total of 1022 acres of cropland are used to produce corn, soybeans, sorghum and wheat. Acreage in the four major soil series are: Adco=58, Leonard=114, Mexico=600 and Putman=250. Six farming systems involving different combinations of crop rotation, tillage methods and agricultural chemicals are evaluated. Farming system 1 is a two-year corn-soybean rotation with high nitrogen and pesticide use and minimum tillage. Farming system 2 is a two-year sorghum-soybean rotation with medium nitrogen and pesticide use and minimum tillage. Farming system 3 is a three-year corn-soybean-wheat rotation with low nitrogen and pesticide use and minimum tillage. Farming system 4 is a two-year corn-soybean rotation with low nitrogen and pesticide use and ridge tillage. Farming system 5 is a two-year corn-soybean rotation with high nitrogen and pesticide use and no tillage. Farming system 6 is a two-year sorghum-soybean rotation with high nitrogen and pesticide use and minimum tillage.

Soil erosion (ρ), nitrate-nitrogen available for leaching (ℓ) and net return (π) are estimated for each farming system. The Universal Soil Loss Equation (USLE) is used to calculate soil erosion rates for the six farming systems on the four dominant soils in the case study farm. USLE uses five factors to calculate soil erosion: rainfall, soil erodibility, slope length and steepness, cover and management, and erosion control practice. The Nitrate Leaching and Economic Analysis Package (NLEAP) model, developed by ARS/USDA, is used to calculate nitrate available for leaching (Follett 1991). NLEAP uses information on farm management practices, soil, climate and agricultural inputs to simulate potential nitrate-nitrogen leaching below the root zone. Per acre net returns are calculated for the six farming systems based on two years of data collected from the case study farm. Gross return is price times yield. Prices are actual crop prices received by the case study farmer. Production costs include costs for seeds, machinery, fertilizers and pesticides. Net returns refer to returns to land, management and overhead, that is, returns to the farmer after paying for seeds, fertilizers, pesticides, and machinery. A summary of the net return, soil erosion rate, and nitrate available for leaching data for each of the six farming systems is presented in Table 1.

RESULTS AND ANALYSIS

Each pair of ρ^* and ℓ^* values is used to solve the optimization problem as defined in (2)-(5) using GAMS. Specifically, both ρ and ℓ are divided into eight respective points, resulting in a total of 64 solutions (8×8). Plotting π against ρ and ℓ shows that a Cobb-Douglas function represents the results quite well. A Cobb-Douglas form is appropriate because it exhibits a competitive relationship between ρ and ℓ. Therefore, the tradeoff surface is estimated from the following regression model.

(6) $$\pi = \eta_0 \rho^{\eta_1} \ell^{\eta_2} L^{\eta_3} + \varepsilon$$

where $\eta_0, \eta_1, \eta_2, \eta_3$ are parameters to be estimated and ε is the error term.

Nonlinear regression model (6) is estimated using **PROC MODEL** in **SAS/ETS**. The estimated equation and some model performance statistics are provided below, where numbers in parentheses are standard errors.

(7) $$\underset{(31.02)}{\pi = 188.7938}\,\rho^{\underset{(.02)}{.0642}}\,\ell^{\underset{(.01)}{.0678}}\,L^{\underset{(.03)}{.8691}} \qquad n = 64, R^2 = .9975, \text{Root MSE} = 1304$$

All coefficients have the expected signs and are statistically significant at the one percent level. The positive sign of η_1 and η_2 indicates that there are tradeoffs between farm income and both reduction in soil erosion and abatement of nitrate available for leaching. Therefore, reductions in soil erosion and abatement of nitrate available for leaching would reduce net farm returns. Figure 2 depicts relations of net return changes to reduction in soil erosion and abatement of nitrate available for leaching for three farm sizes $(L = 500, 750, 1000)$. At a given level of soil erosion, abatement of nitrate available for leaching reduced net return. At a given level of nitrate available for leaching, reduction in soil erosion reduces net return. Total changes in net farm returns are estimated using the following equation (8).

(8) $$d\pi = \frac{\partial \pi}{\partial \rho} d\rho + \frac{\partial \pi}{\partial \ell} d\ell + \frac{\partial \pi}{\partial L} dL = \frac{\eta_1 \pi}{\rho} dR + \frac{\eta_2 \pi}{\ell} d\ell + \frac{\eta_3 \pi}{L} dL$$

Estimates from (8) indicate the reduction in net returns due to a simultaneous reduction in soil erosion, nitrate available for leaching, and total acreage at various initial values of ρ, ℓ, L.

Suppose acreage is not allowed to change $(dL = 0)$. Estimates in the following equation indicate the reduction in net returns due to a simultaneous reduction in soil erosion of one ton per acre per year and nitrate available for leaching of one pound per acre per year $(d\rho = 1, d\ell = 1)$ at various initial values of ρ and ℓ.

(9) $$t = t(\rho, \ell) = d\pi = \frac{\partial \pi}{\partial \rho} d\rho + \frac{\partial \pi}{\partial \ell} d\ell = \frac{\eta_1 \pi}{\rho} d\rho + \frac{\eta_2 \pi}{\ell} d\ell = \pi\left[\frac{\eta_1}{\rho} + \frac{\eta_2}{\ell}\right]$$

The estimated total reduction in net returns are generated at different initial levels of ρ and ℓ for three farm sizes $(L = 500, 750, 1000)$ as provided in Table 2. Similar analyses can be performed assuming $dL = d\rho = 0$ and $dL = d\ell = 0$, respectively, which are not reported here.

Soil erosion and nitrate available for leaching are competitive environmental objectives. Figure 2 depicts the tradeoff between ρ and ℓ at three levels of π, namely, $100,000 (top line), $95,000 (middle line), and $90,000 (bottom line). Which point a farmer would select on a particular iso-return line depends on the costs of erosion and nitrate reduction. In the absence of information on the cost of reducing erosion and nitrate leaching, the point selected on an iso-return line depends on the preferences of the farmer. This analytical framework identifies alternative possibilities for achieving the two environmental goals. Results indicate that enhancing one environmental goal leads to a reduction in the other goal.

Another interesting and important result is that farming systems 1 and 5 are not in any of the 64 GAMS solutions, indicating that these two systems are not favored under any of the three objectives considered for the case study farm. This result may not be interpreted as a conclusion because the analysis is based on only two years of farm records and USLE predictions of erosion rates with no till are generally higher than observed rates.[3]

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[3] Determining differences between predicted and measured erosion rates and modifying process-type models are an important part of the MSEA project. Disciplines such as agricultural engineering are improving the accuracy of erosion predictions. USLE at this point is regarded as the best model for predicting erosion rates in terms of its overall accuracy and ease of use.

Another potential use of the tradeoff information generated in this study is to derive a utility function for a decision maker by presenting the tradeoff information. A decision maker can be asked whether s/he is willing to move between two points that represent efficient combinations of the three objectives. These points are taken from the estimated efficient tradeoff surface rather than chosen arbitrarily. Once a utility function for a particular decision maker is derived, it can be used to identify the most preferred point on the efficient tradeoff surface. While different decision makers can have different utility functions, they all face the same and unique tradeoff surface.

Summary and Conclusions

Net returns are calculated for six farming systems based on two years of actual data collected for a case study farm in north-central Missouri. Soil erosion is calculated for six farming systems on four predominant soils using USLE. Nitrate available for leaching is estimated using the NLEAP computer program. The resulting information is used in a multiobjective programming model to generate efficient combinations of net returns, soil erosion and nitrate available for leaching. A Cobb-Douglas regression model is then estimated from the efficient combinations of the three objectives. Tradeoff frontiers are then derived from the estimated regression model and policy implications are discussed.

Results indicate that there are tradeoffs between farm income and soil erosion and between farm income and nitrate available for leaching. This suggests that both economic and environmental objectives should be considered simultaneously in designing and evaluating farming systems.

Results also indicate that reducing erosion and nitrate available for leaching are competitive objectives, i.e., reducing one objective increases the other. This suggests that environmental objectives need to be coordinated in designing environmental policies. Once environmental objectives are identified for a study area, they must be considered simultaneously. Attaining only one environmental objective can result in non-attainment of another objective. The competition between economic and environmental objectives and among environmental objectives should be considered in future research.

Procedures used in this study represent an efficient way to obtain tradeoff information among economic and environmental objectives. The procedures can be extended to more than three objectives. Advantages of the proposed method increase as the number of objectives increases.

Further research should improve the ability to determine economic and environmental impacts of alternative policy options. The methods and procedures described in this study substantially improve the understanding of the on-farm economic and environmental tradeoffs of interest to farmers and policy makers. Policies designed to balance economic and environmental goals should consider these tradeoffs.

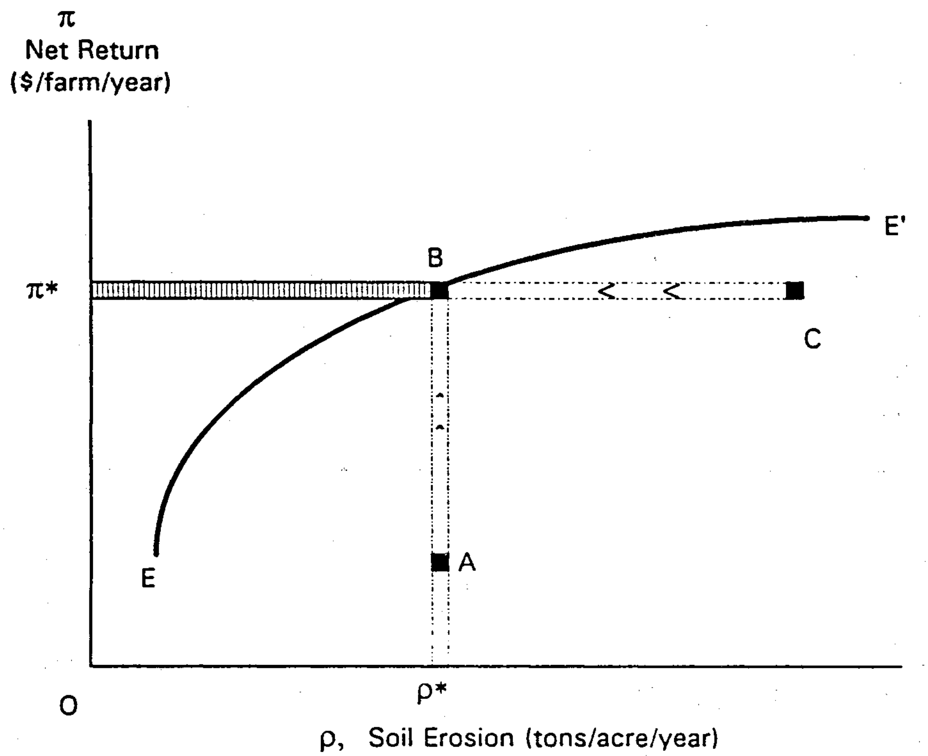

Figure 1. Hypothetical Farm Income -- Soil Erosion Frontier.

Table 1. Estimates of Net Returns, Average Soil Erosion and Nitrate Available for Leaching for Six Farming Systems, Case Study Farm, North-Central Missouri, 1992-1993

Farming System	Soil	Net Return ($/ac/yr)	Erosion (tons/ac/yr)	Nitrate Available for Leaching (lbs/ac/yr)
1	Adco	100.20	1.79	28.8
	Leonard		20.82	23.9
	Mexico		8.47	27.3
	Putman		3.87	27.4
2	Adco	96.63	1.79	7.2
	Leonard		18.74	2.4
	Mexico		7.62	5.5
	Putman		3.48	5.6
3	Adco	96.92	1.16	31.4
	Leonard		14.99	27.8
	Mexico		6.09	30.9
	Putman		2.79	29.9
4	Adco	103.42	1.43	16.2
	Leonard		16.65	13.3
	Mexico		6.77	15.4
	Putman		3.10	14.5
5	Adco	91.77	1.07	27.1
	Leonard		14.57	23.4
	Mexico		5.93	26.5
	Putman		2.71	25.6
6	Adco	108.40	1.79	20.9
	Leonard		18.74	16.2
	Mexico		7.62	19.5
	Putman		3.48	19.6

Table 2. Reduction in Net Returns for Simultaneous Reduction in Erosion (ρ) of 1 Ton/ac/yr and Nitrate Available for Leaching (ι) of 1 lb/ac/yr at Various Levels of ρ and ι ($)

Soil Erosion Rate (t/ac/yr)	Nitrate Available for Leaching (lbs/ac/yr)			
	Farm Size = 1000 acres			
	5	10	15	20
2.5	3546.14	3074.84	2940.59	2886.36
5	2494.01	1942.91	1767.12	1684.69
7.5	2144.62	1559.02	1366.47	1273.06
10	1973.15	1366.46	1164.15	1064.51
12.5	1872.92	1251.28	1042.30	938.49
	Farm Size = 750 acres			
2.5	2761.71	2394.66	2290.11	2247.87
5	1942.32	1513.12	1376.22	1312.02
7.5	1670.22	1214.15	1064.20	991.45
10	1536.67	1064.19	906.63	829.03
12.5	1458.61	974.49	811.73	730.89
	Farm Size = 500 acres			
2.5	1941.53	1683.50	1609.99	1580.30
5	1365.49	1063.76	967.51	922.38
7.5	1174.19	853.57	748.15	697.01
10	1080.31	748.14	637.38	582.83
12.5	1025.43	685.08	570.66	513.83

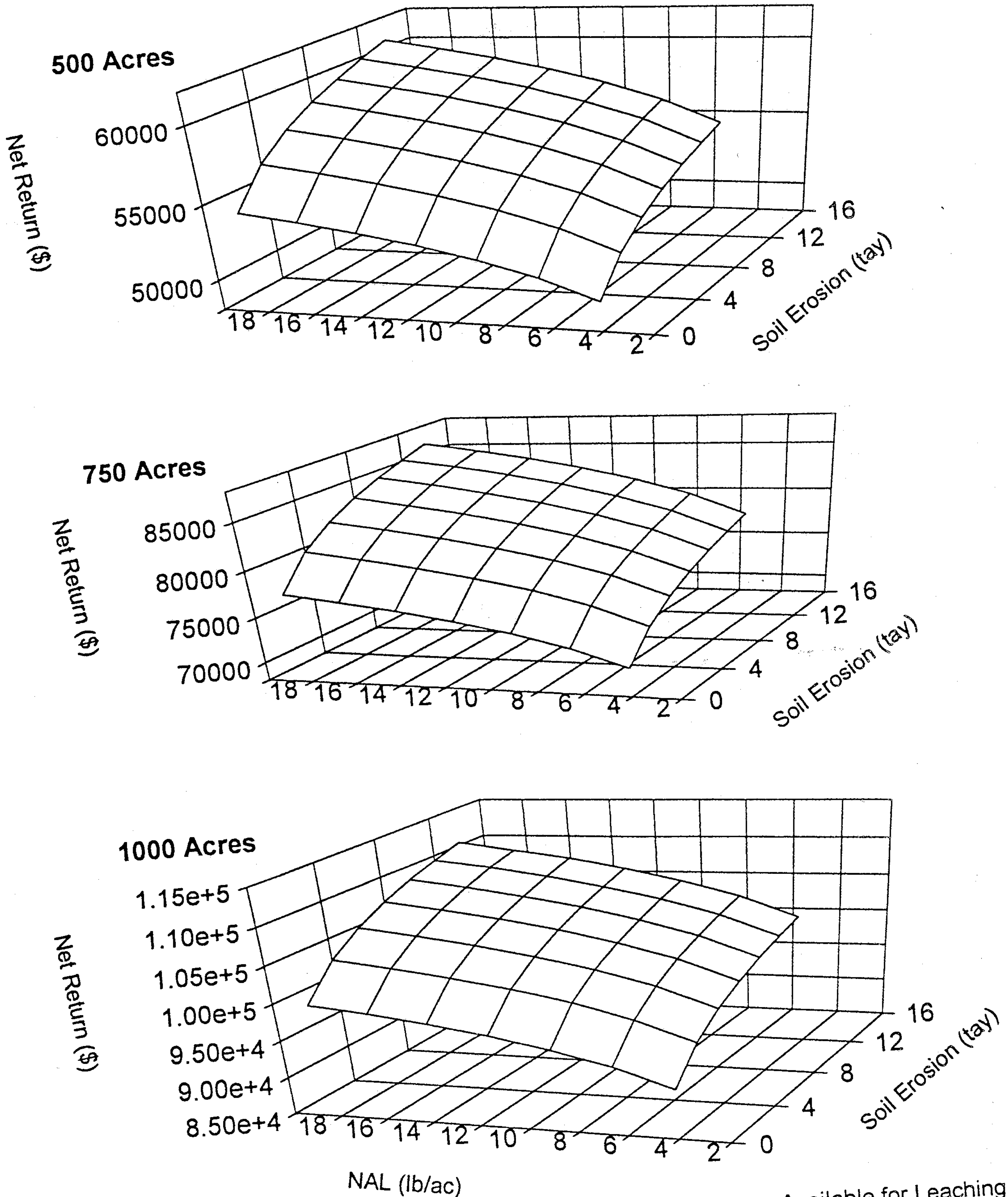

Figure 2. Tradeoff Surfaces of Net Return, Soil Erosion and Nitrate Available for Leaching

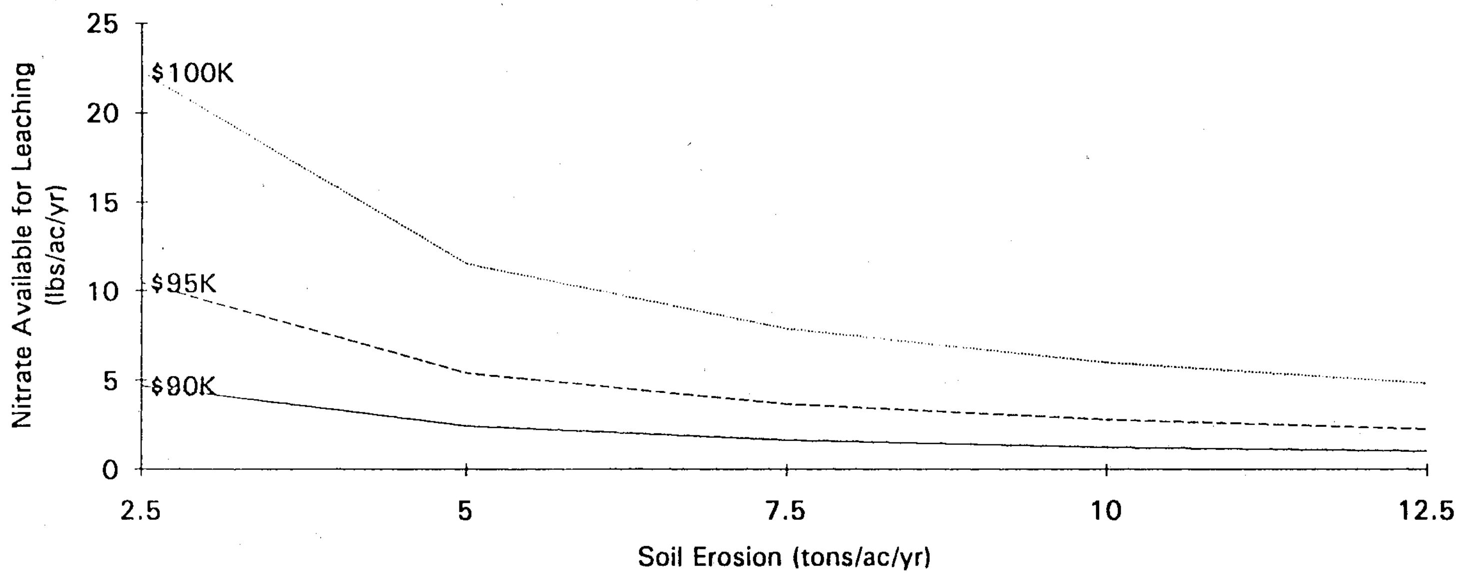

Figure 3. Tradeoff Frontiers Between Soil Erosion and Nitrate Available for Leaching for Alternative Net Farm Returns.

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