Title

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Publication Date

1983-03-01

ECONOMIC POTENTIALS FOR MANAGING NUTRIENT LOSS WITH ALTERNATIVE IRRIGATION TECHNOLOGIES

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The research leading to this report was supported by the U. S. Department of the Interior, under the Matching Grant Program of the Water Research and Development Act of 1978 (P.L. 95-467) as B-209-CAL and by the University of California, Water Resources Center as UCAL-WRC-W-570. Contents of this publication do not necessarily reflect the views and policies of the U.S. Department of Interior nor does mention of trade names or commercial products constitute their endorsement or recommendation for use by the U.S. Government.

TECHNICAL COMPLETION REPORT

March 1983

Abstract

The objective of this project was to examine the economic properties of input taxes and alternative production technologies as instruments for controlling non-point source pollutants. A theoretical analysis demonstrates that input taxes have the economic properties of residuals charges. The use of alternative production technologies is not a promising method for controlling effluents when compared with pollution taxes. Even though inputs may be used more efficiently with new production technologies, controlling technology does not control the quantity of inputs used. The empirical research on nitrate-nitrogen controls in the southern San Joaquin Valley confirms the interchangeable nature of input taxes and residuals charges. Some evidence supporting the second hypothesis was also found since the social costs of requiring sprinkler irrigation were nearly twice the social cost of an equivalent pollution penalty. Furthermore, the results indicated that nitrate losses from cropping activities in some parts of the Central Valley may not be very large.

I. Introduction

Early pollution control efforts centered primarily on point-source emissions problems. Only recently has attention been given to the equally significant problem of non-point source pollution, where the diffuseness of pollution discharges prevents their accurate measurement. Examples from the agricultural sector include water and airborne pesticides, sediments, and percolated salts such as nitrate-nitrogen. Other examples are acid mine drainage, sediments from forestry operations, and chemicals percolated from solid waste disposal.

Most economists prefer a market-like control instruments such as residuals charges (see Langham (1972), Baumol (1972) and Baumol and Oates (1971)). Effective use of emissions fees for non-point source pollutants is difficult, if not impossible, because fees cannot be collected from individual emitters if their emissions cannot be determined. A different type of market-like instrument must be considered in lieu of charges for non-point source pollutants.

The objective of this project was to determine the potential of input taxes on pollution-generating inputs and alternative production technologies which conserve pollution-generating inputs as replacements for residuals charges. Input taxes were identified as a promising alternative since they may retain the desirable economic properties of residual charges. Alternative production technologies were included as another control strategy because of signficiant public policy issues surrounding the Best Management Practice program designated by P.L. 92-500 for control of non-point source emissions. The research had two components. First, a theoretical model was developed to examine and compare the economic properties of each strategy. Second, a linear programming model was constructed to test the theoretical hypotheses for the case of nitrate-nitrogen pollution of groundwater due to agricultural operations in the Lower Tule River Irrigation District.

II. Data and Methods

A. Theoretical Analysis

A general equilibrium approach was used in the theoretical research. Two models, one for the entire economy and another for individual firms, were employed, to examine production decisions in the presence of an external diseconomy. By using classical calculus to develop first-order conditions, the first model yields the conditions for optimal production decisions while the second model determines the behavior of individual competitive firms given a set of market prices.

A general overview of the models begins with the following notation:

Y_{iw} = i^{th} output of w^{th} firm;
X_{jw} = j^{th} input of w^{th} firm;
n_w = pollution output of w^{th} firm;
N = aggregate or regional pollution, i.e., $N = \sum_w n_w$;
P_i = price of i^{th} output;
P_j = price of j^{th} input;
i = 1. . . . u outputs
j = 1. . . . v-1, v inputs
w = 1. . . . s firms

$$F(Y_{iw}) = f(X_{jw}, n_w, N) \tag{1}$$

$$n_w = g(X_{v-1,w}, X_{v,w}) \tag{2}$$

Equations (1) and (2) are, respectively, the production function and a residual production function or pollution generation function. The production function contains a vector of inputs, including pollution-generating inputs, pollution produced by the firm's activities and regional pollution "consumed" by the firm. The presence of the vector of inputs in (1) needs no explanation. Pollution may be viewed as a production input from two perspectives. First, according to the materials balance principle, a complete accounting of the production process must include the component of inputs that are ultimately discharged to the environment as residuals. Second, the firm's pollution output is a proxy for its use of environmental quality as an input (Graaf (1963), Sims (1979), and Smith (1972)). The regional quantity of pollution also enters as a detrimental input by the definition of an externality -- it is imposed irrespective of firm preferences. The negative externality is assumed to be undepletable. Pollution is an input to production but it is also an output of production inputs. Therefore, Equation (2), the residual production function, adheres to the materials balance principle and specifies pollution production from a set of inputs joint with the production function.

Using this initial set of conditions stating production possibilities, the conditions for Pareto optimum production by the entire economy are examined. The Lagrange problem for a Pareto optimum may be written as:

$$\text{Max } A = \sum_w \lambda_w (F(Y_{iw}) - f(X_{jw}, n_w, N)) + \sum_w \gamma_w (n_w - g(X_{v-1,w}, X_{v,w})) +$$

$$\xi(N - \sum_w n_w) + \sum_i \sigma_i (\sum_w Y_{iw} - Y_i) + \sum_j \rho_j (\sum_w X_{jw} - X_j$$

where λ, γ, ξ, σ and ρ are Lagrange multipliers.

The first two terms of Lagrangian equation summarize the output and residuals production possibilities. The third part of the equation constrains regional pollution to be no greater than the sum of pollution by all firms in the region. The fourth constraint prevents the sum of output produced by all firms from exceeding the total amount produced for any given output i. The fifth constraint has a similar interpretation for inputs.

The first-order conditions from (3) must be satisfied for Pareto optimal production in the presence of an externality. These conditions are compared to the behavior of individual firms to determine if a competitive equilibrium can yield an optimum. Three cases are examined: (a) no pollution penalty, (b) a residual charge, (c) a set of input taxes. Primary emphasis is placed on input taxes because they are the most appropriate instrument for non-point source pollution control.

As an example, the Lagrange equation stating the problem of a firm faced with a set of input taxes on residual-generating inputs is:

$$\begin{aligned}\text{Max } Z = \sum_i P_i Y_{iw} - \sum_j P_j X_{jw} - T^{v-1} S_{v-1,w} - T^v X_{v,w} - \mu_w(F(Y_{iw}) - \\ f(X_{jw}, n_w, N)) - \delta_w(n_w - g(X_{v-1,w})) - \chi(N - \Sigma n_w)\end{aligned} \tag{4}$$

where μ, δ, and χ are Lagrange multipliers.

The firm maximizes profits given a set of competitive prices, subject to constraints on its own production possibilities.

A slight alteration of these models was necessary to analyze alternative production technologies as a control method. This was accomplished by including the costs of switching technologies in the

Lagrange equations. An index of technology and efficiency factors for residual-generating inputs were also added to the model.

B. Linear Programming Analysis

Linear programming is a powerful tool for testing the hypotheses developed by the theoretical research because of its ability to handle several levels of water and fertilizer application, along with different irrigation technologies. Since nitrate-laden groundwater supplies are a potential health hazard to both human and animal populations, a programming model was constructed to examine the control of nitrate-nitrogen leaching by input taxes on water and fertilizer or alternative irrigation technologies which conserve these same inputs. The Lower Tule River Irrigation District in Tulare County, California, was selected for analysis. It is similar to other irrigation districts in the southern San Joquin Valley with a wide variety of crops grown using both surface and groundwater applied mainly by surface irrigation methods.

Given ouput and input prices, the model maximizes net revenues per acre for 16 crops subject to constraints on total surface water, total nitrogen losses, total acreage, and individual crop acreages. The programming algorithm selects the most profitable method of growing a given crop from the available combinations of water source, irrigation system and quantities of fertilizer and water. The model, which has 900 activities, may be formally stated as:

$$\text{Max Net Revenue} + \sum_{A}\sum_{B}\sum_{C}\sum_{D}\sum_{E}(P_{A}Q_{ACE} - P_{D}W_{ABC} - VC_{ABCD} - FC_{ABD} - P_{E}N_{AE})X_{ABCDE}$$

Subject to:

(1) $\sum_{A}\sum_{B}\sum_{C}W_{ABC}X_{ABC,2} < SW$ (surface water constraint)

(2) $\sum_{A}\sum_{B}\sum_{C}\sum_{D}\sum_{E}X_{ABCDE} < TA$ (total acreage constraint)

(3) $\sum_{A}\sum_{B}\sum_{C}\sum_{D}\sum_{E}(.0044395\ LF_{B}W_{ABC}N_{AE})X_{ABCDE} < ME$ (total nitrogen loss constraint)

$$A^{L}_{1} < \sum_{B}\sum_{C}\sum_{D}\sum_{E}X_{1,BCDE} < A^{U}_{2}$$

$$\vdots \qquad\qquad \vdots$$

$$A^{L}_{16} < \sum_{B}\sum_{C}\sum_{D}\sum_{E}X_{16,BCDE} < A^{U}_{16}$$

Indexes:

A = index of 16 crops
B = index of 4 irrigation systems
C = index of 3 water application levels
D = index of 2 water sources
E = index of 3 fertilizer application levels

Variables:

P = crop, water or fertilizer price.
Q = yield of crop grown under different water and fertilizer applications.
W = applied water.
N = applied nitrogen.
VC = variable irrigation costs, including energy, labor and repairs.

FC = non-irrigation and fertilizer crop costs, including cultural costs, harvesting costs, overhead and depreciation.
X = acres of crop grown with a given irrigation system, water application level, water source, and fertilizer application level.
SW = total surface water available.
TA = total acreage in irrigation district.
ME = mass emissions of nitrates in pounds per acre.
LF = leaching fraction for each irrigation system.

Aside from the constant returns to scale assumption embodied in the fixed coefficients production structure, the model is like the theoretical models: multiple outpus and inputs and a single externality, nitrate-nitrogen, generated by the variable inputs water and fertilizer.

The crops modeled include 9 field crops, 1 vegetable crop, and 6 orchard crops, with most of the district acreage in field crops. A FORTRAN algorithm computes the net revenue for each crop, irrigation system, applied water, applied nitrogen and water source and also computes constraint coefficients for each activity. A more detailed explanation of the model can be found in Stevens (1982).

Several important components of the model deserve mention. First, a single production function in percentage terms determines the reduction in yield and hence gross revenue, from decreases in applied water and applied nitrogen. The use of a single production function assumes that all crops have the same response to water and nitrogen inputs. Though this assumption is not true, the absence of production functions relevant to the study area for all 16 crops (or even even all 3 crop classes) offered no alternative.

Second, the applied water data is quite important since it affects several of the cost computations. The quantity of applied water for a given crop depends upon a number of factors including climate, soil type, management practices and irrigation system efficiencies. The system efficiencies and leaching fractions used in this study are within the range of efficiencies reported by Batty, et al. (1975) and Hagan and Roberts (1978). A similar range of efficiencies is used by Bisser (1970) and Gisser, et al. (1979).

However, very little is known about the actual efficiencies experienced by growers. Preliminary results from another project conducted in the Central Valley indicate a wide range of variation for each system around the assumed efficiencies but the difference in the mean efficiencies for each system are not large. These results should be cautiously interpreted since the data has not been completely analyzed but they suggest that management characteristics are at least as important as the irrigation system in determining a grower's experience regarding efficiency. Furthermore, it suggests that the actual efficiencies should be used if they are known, although the assumed efficiences are suitable for present purposes.

Third, the individual crop acreage constraints unit crop shifts to plus or minus 10% of the acreage for 1979, the year from which the price data was taken. If the diversity of crops in the district is due to the risk-averse behavior of farmers, even relatively large changes in output and/or input prices may not induce significant crop shifts. This is particularly true for orchard crops such as almonds, walnuts and grapes due to the time lag of developing new acreage. Uncertainty generated by the volatile nature of crop prices may also prevent a rapid response by growers.

Finally, nitrate emissions are calculated according to the following equation:

$$N_L = .0044395\ N_A\ w \qquad R^2 = .90 \qquad F = \underset{***}{151.46} \qquad n = 17 \tag{5}$$

N_L = nitrate-nitrogen losses in pounds per acre

N_A = nitrogen applied in pounds per acre

W = drainage water volume in acre-inches per acre

This equation was estimated from data in Letey, et al., (1977). The data was gathered by monitoring 17 tile-drained site locations in California. Though the sample size is not large, the fit of the equation is quite good. The Goldfeld/Quandt test for heteroscedasticity was performed (Goldfeld and Quandt, (1965)), resulting in a rejection of the hypothesis of heteroscedasticity. Due to the nature of the test, the small sample size may have contributed to this result. Field trials being conducted by Dr. J. Letey and W. Jarrell at U.C. Riverside may provide additional data for estimating nitrogen losses from agricultural operations.

The model uses data from various sources. For example, gross revenue and individual crop acreages were obtained from the U.S. Bureau of Reclamation. Fertilizer and irrigation-related costs were netted out of costs given by crop budget sheets form the University of California Co-op Extention. The remaining costs are the fixed cost of growing any given crop. The base price for fertilizer, exclusive of application, was also obtained from the budget sheets. Applied water costs are different for each source. An average surface water price of $11.58 per acre foot is used while groundwater costs, which are a function of total lift, pump efficiency and the cost of pumping energy, are $34.72 per acre foot. The four irrigation systems used are flood, furrow, hand-move sprinkler and drip irrigation. Fereres, et al. (1978) provided the data on fixed and variable irrigation costs. These costs differ by water source due to investment and operating and maintenance cost of a well for groundwater. Variable system costs include labor, maintenance and repairs while fixed costs are merely the capital cost of a system. Rauschkolb and Mikkelson (1978) provided data for fertilizer applications.

III. A Theoretical Result

The first-order conditions from (3) demonstrate that optimal use of residual-generating inputs requires firms to account for the value of marginal pollution damages incurred by other firms caused by the use of inputs which generate pollution. Furthermore, the input's value marginal product not only includes the input's physical capability to produce output but also its capability to generate pollution.

Subsequently, three control strategies are analyzed: (a) no pollution penalty (b) a residual charge (c) a set of input taxes. First-order conditions from (3) to determine if the behavior of firms under any of these strategies can satisfy the conditions for optimality. As expected, the first strategy is not compatible with the conditions for an optimum because firms have no incentive to account for damages to other firms due to residual-generating input use.

Several previous efforts have established that a residual charge set equal to the value of marginal pollution damages would satisfy the conditions for optimality (see, for example, Baumol and Oates (1975)), a result confirmed this study. The first-order conditions also revealed that a residual charge would implicitly increase the price of residual-generating inputs such that the conditions for optimal input decisions are also met.

Indirectly penalizing firms by taxing residual-generating inputs can also satisfy the conditions for optimality. This control method works because even though pollution itself is unpriced, the price of residual-generating inputs is increased by the imposition of a set of input taxes relative to the situation where there is no penalty on pollution. For any pollution-generating input, an input tax equal to the value of marginal damages from a unit of pollution times the input's marginal residual product, internalizes the externality since the firm uses inputs in optimal proportions and produces an optimal quantity of pollution. The concept of the marginal residual product is similar to that of marginal physical product except that it refers to the input's capacity to produce pollution. Thus, the input tax merely serves as a price for the input's ability to pollute.

One extremely important implication of this result is that a relationship between an optimal charge and an optimal set of input taxes exists since the optimal input tax can be determined by multiplying the optimal charge by the marginal residual product. Therefore, most of the theoretical results in the literature pertaining to the use of residual charges may be readily extended to input taxes since the two instruments can equivalently reduce pollution. Extending the model to three additional cases, specifically, an environmental pricing approach, spatial detail and depletable externalities, reinforces this conclusion.

Several other important results were also demonstrated. Input taxes should lead to a reduction of all outputs for a multi-product firm but a relative larger reduction of outputs which are intensive users of residual-generating inputs should occur since their marginal cost curves are shifted further to the left. Also, since the marginal residual product is usually less than one, input taxes will be lower than the corresponding charge. Although charges and input taxes are marginally equivalent, total charges collected will equal total input taxes paid only if the residual generating function is linearly homogeneous. If the degree of homogeneity is greater than one, total residual charges will be less than total input taxes collected. Finally, if soil type differs between firms, a uniform set of input taxes cannot be optimal while a variable set of input taxes adjusted by soil type can satisfy the conditions for optimality. Intuitively, this result means that pollution control can be achieved at a lower cost to society by taking advantage of natural assimilative capacity due to soil type.

Although input taxes can be used in place of charges for control of non-point source pollutants, their information requirements are greater than charges. In particular, the residual-generating function must be known in order to determine the relationship between input use and pollution output. The companion study to this project being conducted by Drs. Letey and Jarrell will provide information necessary to construct this function for nitrate-nitrogen. In addition, since the market input(s) demand and supply function(s) jointly determine the input tax necessary to induce a specified input reduction, some knowledge of these functions is required to implement a system of input taxes. In particular, some estimate of the supply and demand elasticities is necessary since they determine the magnitude of the input tax.

Although it is likely that shifts in production technology would be forthcoming with either type of pollution penalty, the initial model could not shed any light on such a response because production technology is implicit. Some slight modification to the model allowed technology to be explicitly considered as a choice variable by the firm. More efficient technologies were assumed to conserve polluting inputs but a cost is attached to switching to new technologies. The same analytical procedure was followed. First order conditions from a model of the entire economy were developed to determine the conditions for optimum production, including choice of technology. These conditions were compared to those characterizing the behavior of firms under three alternative pollution control strategies: (1) a pure technology control method (2) a residual charge (3) a set of input taxes.

The conditions for optimal production again showed that the value of marginal damages to other firms is an important factor to be considered in determining input quantities. Technology, however, governs the efficiency of residual-generating input use. In choosing a technology, the imputed value of switching costs should be equated with the value of the net output change, reduced input costs and the value of additional output by other firms due to residual-generating input reductions. Since technological conservation of externality-generating inputs benefits other firms, the firm's calculus for the choice of technology must include this factor along with net output and input cost effects.

It was determined that a pure technology control strategy is not sufficient to satisfy the conditions for an optimum. This is due to two factors. First, since switching to more efficient technologies is not a costless activity, firms will ignore damages to other firms from pollution-generating inputs in deciding how much to spend on technological conservation of such inputs. In short, the firm will only increase expenditures on technology to account for damages to other firms if there is a financial incentive to do so. Second, the input quantities chosen are not optimal. This is due partly to the fact that residual generating inputs are used inefficiently with an incorrect choice of technology in the abesence of a pollution penalty. The damages incurred by other firms must also be considered. Without a pollution penalty, inputs are undervalued in relation to their social value. As a result, too much of any residual generating input will be used even when the appropriate technology is selected. The same conclusion can be drawn from a model of environmental pricing or a model where technology itself is constrained.

The conclusion has extremely important public policy implications. Designating the production technology to be used by polluters is an ineffective pollution control method. Intuitively, the reason is straightforward--controlling technology does not control the quantity of inputs used. Even though technology is fixed, the scale of output and input use is left up to the firm, and any given technology covers a broad range of input/output combinations. This conclusion also applies even to a fixed coefficient production technology since fixing the technology determines the input proportions (or the input per unit output) but the quantity of inputs used depends on the profit-maximizing level of output which is a function of output price. Where input substitution possibilities exist, input quantities are also influenced by input prices. A pure technology control method must be accompanied by either direct input controls or by a pricing method which directly or indirectly affects the price of externality-generating inputs. The Best Management Practice program, particularly as it is emerging in irrigated agriculture (see Evans, et al. 1980), can be reasonably iterpreted as a pure technology control method. These results imply that the program, even if successfully implemented, will fail to adequately control nonpoint source emissions.

The analysis shows that implementation of either residuals charges or input taxes will result in an optimum. In either case, the pollution penalty may induce the firm to switch to more efficient production technologies as it seeks to reduce residual charges or input tax payments. In this way, the firm accounts for the value of marginal damages incurred by other firms in its choice of technology.

Three other useful results have been obtained. First, if growers perceive the cost-sharing element of the BMP program as a per unit subsidy on technology, technologies which are too efficient are adopted because farmers do not have to pay their full cost. From a social viewpoint, too much is spent on technology and society bears part of this cost in the form of the subsidy. Second, pollution control authorities require _a priori_ some knowledge of the technological shifts which are induced by either type of pollution penalty if an optimum is to be approached directly rather than through reiteration. The presence of this requirement for additional information confirms Baumol and Oates' (1971) conclusion on the infeasibility of administering optimal residual charges. The same conclusion also applies to input taxes. Third, an examination of the impact of different soil qualities shows that firms which have unfavorable soil types may initially have higher input prices due to higher input taxes. However, there is an incentive to offset the lack of natural soil assimilative capacity with technology so as to reduce input tax payments. Utilization of relatively efficient technologies can reduce the optimal set of input taxes for firms which have poor soil types and could eliminate the input tax differential entirely. As a consequence, there is no justification for utilizing discriminatory taxes that reflect differences in soil quality or locational differences.

III B. Linear Programming Results

The linear programming model was used to test two hypotheses that emerged from the theoretical work.

(1) That input taxes can achieve the same reduction in pollution as an equivalent charge, where equivalence of the two instruments is given by the marginal residual product of pollution-generating inputs.

(2) That pure technology control methods, for example designating sprinkler irrigation to be used on all crops, cannot achieve a standard as efficiently as a set of input taxes.

Verification of the first hypothesis would demonstrate that a residual charge and a set of input taxes are interchangeable pollution control instruments which elicit identical responses from economic agents. The second hypothesis, if it is true, would confirm that a BMP program which relies primarily on technology to control non-point source pollution is an inefficient control strategy compared to input taxes.

The empirical results show that an equivalent set of input taxes results in a slight reduction of total nitrate losses. Closer examination of the results reveals a decline in the applied nitrogen level for peaches, one of the most fertilizer intense crops. This occurred because of a combination of factors. First, since (5) is homogeneous of degree 2, total input taxes collected will exceed total residual charges. Therefore, profits for individual crops and for the region will be less under a system of input taxes. Second, the marginal residual product and production function are piecewise linear because of discrete water and fertilizer applications and hence, profits are also piecewise linear. Profits decline more on peaches than on other crops because of its relatively higher water and nitrogen requirements. The additional variable costs from an equivalent set of input taxes make the lowest level of fertilizer application the most profitable activity whereas the medium fertilizer application is not profitable when a residual charge is used. The first hypothesis thus cannot be proved.

Though the hypothesis is not proved, the result is encouraging since it may be attributable to the restrictive linearity assumptions underlying the model. Adding one more water and fertilizer application level each might alleviate this problem since the linear segments would more closely approximate the nonlinear production function. However, this solution nearly doubles the number of activities in the model. Given the limitations of the model, it can be provisionally concluded that residuals charges and input taxes do result in the same quantity of emissions.

The equivalent set of input taxes cannot be put into practice because each tax depends on the quantity of the outer input. For example, the nitrogen tax depends on the drainage volume which is a function of the crop and irrigation system. This result occurs because the multiplicative form of the residual production function which causes the marginal residual product to be dependent on the other factors that influence pollution. In this case, input taxes are nonuniform and cannot be enforced.

An approximation to the equivalent set of input taxes was computed by using an average for applied nitrogen and drainge volume. The results showed a 15% increase in nitrate emissions due to a moderate increase in fertilizer applications and applied water. It is difficult to approximate an efficient set of input taxes because the average nitrogen or drainage volume will change each time the set of input taxes is changed. This finding illustrates that there are substantial information requirements associated with the formulation of an optimal set of input taxes.

The second hypothesis was tested by constructing a model in which sprinkler irrigation was the only available technology and comparing outcomes with those of the original model. The baseline results when only sprinkler irrigation was used show that nitrate emissions are reduced by nearly 50% while district profits drop by 55% due to the additional fixed costs of sprinkler irrigation. Nitrates were constrained below the sprinkler only baseline level in both models in order to generate shadow price for nitrate leaching. No shadow price emerges if nitrate losses are left unconstrained. The shadow price of nitrate losses was greater when all four systems were available than under sprinkler irrigation. This apparent contradiction of the second hypothesis is readily explained by the fact that the value of a marginal unit of nitrate emissions is higher precisely because profits are larger when a choice of systems is allowed.

However, this finding does not imply that the BMP program is a superior control instrument to pollution penalties. A tax penalty on pollution reduces district-wide profits more than mandated irrigation technology. However, the tax revenues from the penalty represent a transfer payment, not a net loss to society. The result is that the total social costs of mandated technology are $7 million while the social costs of input taxes are only $3.8 million.

Finally, the effect of variations in the nitrate loss function were examined. With the loss function estimated from the data of Letey _et at._, 1977, total baseline emissions were about 200,000 pounds or roughly 2.25 pounds of nitrate leached per acre. The quantities of fertilizer and water estimated with the model were approximately equal to those prevailing in the study area. At a minimum, this suggests nitrate losses are regional or site specific. A loss function estimated by Pfeiffer (1976) from the data of Pratt and Adriano (1973) produced estimates of nitrate loss three to five times larger than the function based on the data of Letey _et al_. The Pfeiffer function could not be analyzed further because of the absence of information on its statistical properties. Nitrate losses are initially more responsive to a penalty with this loss function for a given percentage reduction in emissions. Pollution penalties are lower since the situation is analogous to an outward shift of a supply function, in this case, a supply curve for environmental quality. Social costs are relatively equal with both loss functions since adjustments in cropping activities to reduce pollution are nearly the same. However, profilts are more severely eroded with the Pfeiffer loss function because the absolute quantity of emissions is larger.

Three important conclusions emerge from this portion of the research. The initial conclusion that nitrate losses are not large for this district is further supported. The effect of the alternative loss function on nitrate losses is much greater than changes in the data on nitrogen and water applications. Even with Pfeiffer function, nitrate losses are at a level that most soil scientists would consider low. Thus, corrective action by a Section 208 agency is probably not necessary.

Second, other Districts may have a significant nitrate leaching problem caused by a combination of characteristics that are not present in this District. For example, the crop mix in Lower Tule includes a substantial portion of acreage in crops that have moderate rates of fertilizer and water application. Alfalfa and dry beans have no nitrate losses since they receive no fertilizer, yet they constitute nearly 20% of the total acreage. Districts which have a large proportion of orchard or vegetable crops may contribute heavily to nitrates in groundwater because of more intense use of fertilizer and water inputs. The presence of soils with rapid infiltration rates may have a crucial effect since both applied water and drainage volumes are increased on such soils. Low priced water or other disincentives intensive water management may also lead to large nitrate losses.

Thirdly, the results summarized above indicate that conclusions as to the efficient levels of control are crucially influenced by the nature of the nitrogen loss function. It is important that nitrate losses be estimated as accurately if perverse regulatory outcomes are to be avoided. In particular, an optimal set of input taxes cannot be estimated and their effects cannot be assessed unless nitrogen losses can be simulated accurately.

The importance of this problem depends ultimately on the magnitude of the difference between estimated and actual nitrate losses. The two nitrate loss functions examined suggest that there is potential for large errors. Although soil scientists have performed extensive research on this subject, no definitive nitrogen loss function has emerged. For example, Pratt (1982) reports several different nitrate loss functions, none of which appears superior to the others. Clearly, the lack of agreement on this issue makes it difficult, if not impossible, to formulate policy for controlling nitrates.

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