Reducing Nutrient Application Rates for Water Quality Protection in Intensive Livestock Areas: Policy Implications of Alternative Producer Behavior

William T. McSweeny and James S. Shortle

High rates of commercial fertilizer and animal manure application on cropland have been identified as an important cause of ground and surface water degradation in many areas of the country. Suggested remedies are often based on the idea that fertilization levels are economically irrational for the individual farmer. The received wisdom is that farmers could simultaneously improve their own economic well being and reduce the degradation of the ground and surface waters by fertilizing only to meet crop nutrient needs. Rather than assuming that farmers act irrationally, this study examines the fertilization problem on a mixed crop-livestock farm from the perspective of a risk-averse farmer coping with two key uncertainties: crop yield response to nitrogen applications and the nitrogen content of manure. The effects on fertilization decisions by such a farmer of various policy prescriptions for reducing surface and ground water pollution are examined. The results underscore the importance of understanding producer behavior for the design of economically sound policy.

Surface and groundwater quality problems associated with crop nutrient management in agricultural are receiving considerable attention as policy makers shift their efforts from point to nonpoint pollution control (Crowder and Young; Kashmaian, *et al.*). Nutrient runoff from farms plays a major role in the accelerated eutrophication of lakes and estuaries in many areas of the country, including such significant water bodies as Lake Champlain, the Great Lakes, Chesapeake Bay, and San Francisco Bay (U.S. Environmental Protection Agency, 1984). In addition, nitrates are a common groundwater pollutant that can harm human and animal health.

The design of economically sound policies for reducing nutrient losses from farms requires consideration of how farmers may respond to alternative policy approaches and the farmers' costs of control. Public programs now implemented in several regions of the country including the Northeast presuppose that farmers apply crop nutrients in excess of what is required for profit maximization. A major thrust of public policy in these regions is to reduce nutrient runoff by persuading farmers that they could benefit financially from reduced fertilization rates (Swartz; Young and Magelby).

The potential effectiveness of this policy approach is economically suspect since it is based on the uneconomic, although not necessarily incorrect, notion that farmers systematically choose to fertilize in a manner inconsistent with their own best interests. While farmers may apply nutrients at rates in excess of those required to maximize profits, risk could induce such behavior (e.g., Pope and Kramer). Many farmers exhibit risk-averse behavior, sacrificing income for reduced risk (Lin, Dean, and Moore). Yield risk and its response to fertilizer are recognized as key factors in the economics of fertilization (e.g., de Janvry).

With few exceptions, past studies of nutrient management for water quality protection have assumed risk-neutral, expected profit maximizing behavior (e.g., House, *et al.*). This study examines nitrogen application and its response to several public policies for reducing nutrient losses from agricultural land from both expected profit maximizing and safety-first behavioral frameworks. A chance-constrained mathematical programming model of a hypothetical farm is used to implement the safety-first analysis. The expected profit maximizing framework is a special case of the chance-constrained

---

The authors are Assistant and Associate Professor, respectively, in the Department of Agricultural Economics and Rural Sociology at Penn State University. The authors wish to express their thanks to two anonymous reviewers whose comments helped shape the final draft. Journal Series No. 8141 of the Pennsylvania Agricultural Experiment Station.

model. The numerical structure of the model is based on dairy farm practices in Lancaster County, located in southeastern Pennsylvania.

The purpose is to demonstrate the possible sensitivity of policy evaluations to assumptions concerning farmer behavior. The safety-first framework is one of a number of alternative approaches for analyzing decision-making under uncertainty. It is not presented here as the most appropriate framework but only as one that is plausible and interesting in the context of the excess fertilization problem (de Janvry). Two uncertainties of importance in nutrient management on mixed crop- livestock farms are considered: uncertainty about the response of crop yields to fertilization and uncertainty about the nutrient content of manure. The plant-available nutrient content of manure depends not only on the feed ration, but the handling and storage systems used, bedding, time of year that it is applied, and many other factors. Hence, the variability of the available nutrient content between loads applied to the soil can be substantial.

It has been reported that in southeastern Pennsylvania, farmers apply 17 million pounds of nitrogen in excess of the amounts required for maximum crop yields (Abdalla, *et al.*). The U.S. Environmental Protection Agency (EPA) has identified nutrient runoff from this area of highly intensive dairy, swine, and poultry production, as a major factor in the degradation of the Chesapeake Bay. The nutrient run-off has been targeted for intensive control efforts by state and federal authorities (U.S. EPA, 1983).

Analytical Framework

Uncertainty about crop response to nitrogen, and the nitrogen content of manure represent uncertainties about input-output and input substitution relationships. The effect of these uncertainties on the choice of farm plans depends on the farmer's objectives, subjective risk perceptions, and attitudes toward bearing risk. Within the safety-first framework, risk-aversion corresponds to a statement of probability that characterizes the chances that the individual farmer is willing to accept of not meeting the nutrient requirements of crops and the desired end use of crops (de Janvry). Expected net returns are maximized provided that the probabilistic constraints are satisfied. A model of this type has intuitive appeal and is computationally attractive for analyzing farm management with stochastic technology (Hazell and Norton; Paris and Easter; Roy; Katoka; Telser; Shackle). In addition, the implied behavior is consistent with observed practices in the study area (Abdalla, *et al.*).

Assuming an activity analysis type of technology, the farmer's problem is assumed to be as follows:

$$(1) \quad \text{Max } E(p)'x$$

$$(2) \quad \text{s.t. } A_i'x \leq b_i,\ i = 1, \ldots, t,\ t < m$$

$$(3) \quad \Pr[A_i'x \leq b_i] \geq \alpha_i,\ i = t + 1, \ldots, m \quad x \geq 0$$

where $E(p)$ denotes a $n \times 1$ column vector of expected net unit activity returns, x denotes an $n \times 1$ column vector of unit activity levels, A_i denotes the i^{th} row of a $n \times m$ matrix of technical coefficients, b_i denotes the i^{th} element of a $m \times 1$ column vector of resource supplies, Pr denotes probability, and α_i denotes the minimum probability of satisfying the i^{th} constraint. The stochastic technical coefficient vectors A_i, $i = t + 1, \ldots, m$ are distributed with mean $E(A_i)$ and variance Ω_i. Constraint (3) requires that the stochastic use of the i^{th} resource not exceed resource availability, b_i, with a probability of at least α_i.
By standardizing the arguments of (3), the problem can be restated as a chance-constrained mathematical programming problem (Charnes and Cooper):

$$(4) \quad \text{Max } E(p)'x$$

$$(5) \quad \text{s.t. } A_i'x \leq b_i,\ i = 1, \ldots, t,\ t < m$$

$$(6) \quad E(A_i)'x + \theta(\alpha_i)(x'\Omega_i x)^{1/2} \leq b_i,\ i = t + 1, \ldots, m$$

where $\theta(\alpha_i)$ represents the point on the corresponding density function where the i^{th} constraint will be satisfied with a probability of α_i. The constraint set given by (6) is convex if Ω_i is positive semidefinite (Paris and Easter). Optimal solutions to this problem can be obtained using nonlinear algorithms such as those in MINOS (Murtaugh and Sanders).

Note that where $\theta(\alpha_i) = 0$, (6) becomes a linear constraint and the problem is equivalent to conventional expected profit maximization. On the other hand, where $\theta(\alpha_i) > 0$ and Ω_i is positive definite, (6) implies that planned use of the ith resource is less than the amount available leaving a margin of safety between expected use and availability in the optimal plan. Hence, safety-first decision making is one possible framework which could lead to purposeful "over application" of nutrients.

In this analysis corn grain and silage yields, and the nitrogen content of manure are stochastic. The constraint for corn grain involves sources (production and purchase) and end uses of corn grain (selling and feeding). This constraint is written generally as

$$(7) \quad PR[-a_{ij}x_j - a_{ij+1}x_{j+1} + a_{ij+2}x_{j+2} + \ldots + a_{ij+t}x_{j+t} \geq p] \geq \alpha$$

where x_j and x_{j+1} are feeding and selling activities respectively, and x_{j+2} through x_{j+t} are production and purchasing activities. The constraint requires that the total production and acquisition of corn grain be no less than total end use, with a probability of at least α_i. Within this constraint, the only technical coefficients treated as stochastic in this study are those pertaining to corn grain production. It is evident from the above discussion that a safety margin will exist between expected yield and use in an optimal plan where $\theta(\alpha_i) > 0$ and Ω_i is positive definite for the corn grain constraint.

Corn silage is treated in the same manner. It is important to note here that there is no market for this important feed in the area used for this study. Accordingly, other things being equal, safety-first behavior should lead to a larger allocation of acreage to corn silage production than expected profit maximizing behavior.

The constraint involving manure nitrogen depicts sources of nitrogen to crops and crop nitrogen requirements. This constraint is written as

$$(8) \quad PR[-a_{lh}x_h - a_{lh+1}x_{h+1} + a_{lh+2}x_{h+2} + \ldots + a_{lh+s}x_{h+s} \leq 0] \geq \alpha_i$$

where x_h and x_{h+1} are manure nitrogen and purchased nitrogen inputs, respectively, and x_{h+2} through x_{h+s} are crop production activities. The constraint requires that total nitrogen availability be at least as large as crop nitrogen needs, with a probability of at least α_i. Within this constraint, the only technical coefficient treated as stochastic in this study is α_{lh}, the expected nitrogen content per ton of dairy manure. The positive definiteness of Ω_i and $\theta(\alpha_i) > 0$ imply that the nutrient content of manure will be discounted to provide a safety margin in supplying the nutrient requirements of crops in an optimal plan.

Farm Model

The farm model consists of 75 acres of cropland, allocated among corn grain, corn silage, and alfalfa hay. All land was assumed to be Hublersburg silt loam. Manure was assumed to be spread on a daily basis, so that all fields receive manure some time during the year. Daily spreading is the most common manure handling process in the study area (Young, *et al.*, 1986).

The dairy herd is limited to 75 cows. Replacement heifers are constrained to two-thirds the number of cows, a ratio common in Pennsylvania dairy herds. Animal nutrient requirements are met through a fixed ration of corn grain, corn silage, and alfalfa hay. The ration is formulated to maintain a 1,320 lb. Holstein cow producing 14,300 lb. of 3.5% fat-corrected milk annually. The heifer ration is formulated for a 600 lb. heifer, as an average weight over the two-year period from birth to freshening. A fixed ration in feeding dairy animals is common in the study area.

The fixed cow-heifer ratio make it possible to convert animal numbers to animal units (AU). Animal units are determined by dividing body weight by 1,000 lb. Thus, the fixed cow-heifer ratio implied 1.72 AU per cow, for a maximum of 129AU on the farm. Furthermore, the 1.72 AU per acre of cropland assumed in the farm model is typical of dairy farms in the study area.

Corn grain and silage production activities are distinguished in the model by rotation (continuous corn or corn after alfalfa), tillage methods (conventional, minimum, and no-till systems), and fertilization rates (high, low, medium). In the absence of data on farmers' subjective yield distributions, mean corn grain and silage yields and variances for each fertilization rate used in the deterministic equivalents of the probabilistic constraints are based on quadratic nitrogen response functions estimated from experimental data taken from Fox and Piekielek. The data were collected from 60 sites across Pennsylvania, including several in the study area. Hence, the data depict the response of corn to nitrogen application under a variety of Pennsylvania conditions, farming practices, and soils.

The response functions for corn grain and silage were estimated using weighted least squares. The weighted least-squares procedure was necessary to control for heteroskedasticity detected with a Park-Glejser test (Judge, *et al.*). The estimated corn grain response function is

$$(9) \quad \underset{(0.192)}{CGY = 2.672} + \underset{(6.342)}{13.518N} - \underset{(52.561)}{54.407N^2} + \underset{(0.066)}{0.105S} + \underset{(0.668)}{0.015M} + \underset{(0.078)}{0.375MT} + \underset{(0.078)}{0.45NT}$$

where CGY denotes corn grain yield (tons per acre); N denotes nitrogen application rate (tons per acre); S denotes a binary variable for soil type (1 if Hublersburg silt loam, 0 otherwise); M denotes a binary variable for manure history (1 for previous year manure application, 0 otherwise); MT denotes a binary variable for tillage practice (1 if minimum till, 0 otherwise); and NT denotes a binary variable for tillage practice (1 if no-till, 0 otherwise). The numbers in parentheses denote standard errors.

The nitrogen requirement consistent with maximum per acre corn grain yield for each tillage type was computed from (9). Three alternative nitrogen application rates for corn grain and silage are used to define crop production activities in the farm model. One-half of the nitrogen requirement for maximum yield was defined as a "low" application rate. The yield-maximizing amount of nitrogen computed from (9), was defined as a "medium" application rate. One-fourth more nitrogen than the medium rate was defined as a "high" application rate. These alternatives are used to define separate activities in the model, each having specific nitrogen requirements, expected yield, and yield variance. Intermediate applications can be formed by linear combinations of these activities to provide a broad range of diminishing marginal returns to nitrogen, including a range with negative marginal product from very high application.

The estimated response function for corn silage is:

(10)

$$CSY = \underset{(0.321)}{4.471} + \underset{(10.608)}{19.932N} - \underset{(37.91)}{103.931N^2} - \underset{(0.111)}{0.038S} - \underset{(0.113)}{0.249M} + \underset{(0.130)}{0.210MT} + \underset{(0.131)}{0.409NT}$$

where CSY denotes corn silage yield (tons per acre); and all other variables are as defined previously. As with corn grain, "low-," "medium-," and "high-" application rates were determined for each tillage type using (10).

It should be noted that the level of nitrogen required to reach a given point on the response curve is not all used by the crop. Plant up-take does not account for all the nitrogen applied to the soil, even if the application is in strict accordance with soil test recommendations. A percentage of the nitrogen applied, regardless of the application level, will be lost to the environment either through volatilization, denitrification, or leaching. Hence, the term "excess" as used in this study to describe nitrogen losses to ground and surface waters, is the amount over and above agronomic recommendations based on soil test results.

The mean (5.5 lb./ton) and variance (121) of the nitrogen content per ton of dairy manure are based on manure analyses reported in Lindley and Johnson. To facilitate analysis, the farmer's subjective distribution was assumed to be normal and match the objective distribution reported in Lindley and Johnson.

Solving the chance constrained problem defined by (4) – (6) requires suitable values of α_i, $i = t + 1, \ldots, m$. Values of $\alpha_i = 0.5$ would imply a value of $\theta = 0.0$ for any symmetric distribution. In this case, the model reduces to a linear programming model, implying a conventional expected profit maximizing framework. Larger values of α_i, by construction, imply tighter constraints and therefore a smaller expected income. Values of α_i approaching 1.0 could over-constrain the model, resulting in infeasibility. For the purposes of illustration, values of $\alpha_i = 0.0$ and 0.95 are considered, the former implying risk-neutral, expected profit maximizing behavior and the latter strong risk aversion as the concept is used in this context.

Baseline Results

Table 1 presents selected characteristics of the expected profit-maximizing and safety-first baseline solutions of the farm model. These solutions illustrate the farm management implications of the safety-first behavior with respect to the manure-nitrogen-content and crop-yield-response risks *vis-a-vis* expected profit maximizing behavior. In the expected profit maximizing solution, the farm is highly animal intensive with 129AU. Cropland is allocated mainly to corn silage production, with a smaller portion used to grow corn grain. Approximately 15 cwt. of nitrogen fertilizer is purchased to supplement the cow manure to supply the expected crop nitrogen requirements.

The farm plan obtained under the assumption of safety-first behavior is quite different from the expected profit maximizing case. The farm is less animal intensive and all acreage is allocated to corn silage. The reason for the shift to corn silage as indicated previously, is the importance of corn silage in the dairy operation and the lack of a market for this feed. The reduction in animal intensity reduces the cost of meeting the silage constraint by reducing feed requirements.

The average rate of nitrogen application per acre is substantially greater under safety-first behavior (see table 2). The per acre requirement in the expected profit maximizing solution is 167 lbs., of which 148.52 lbs. is supplied by manure and the remainder is supplied by commercial nitrogen. The per acre requirement in the safety-first solution is 154.20 lbs., almost 13 lbs. less than required in the expected profit maximizing plan. In the safety-first case, however, the combined effects of the two uncertainties lead to the purchase of 96.39 cwt. of commercial nitrogen, an average of 128.52 lbs. per acre. The farm has 142.81 lbs. per acre of

Table 1. Expected Profit Maximizing and Safety-First Base Solutions

Activities	Units	Expected Profit Maximizing	Safety-First
Dairy Stock	AU	129.0	125.74
Manure Spread on Cropland	tons	1,998.0	1,947.54
Expected Manure Nitrogen	cwt.	109.89	107.11
Purchased Nitrogen	cwt.	15.36	96.39
Expected Nitrogen Excess	cwt.	0	88.15
Corn Grain	Acres	12.24	0
Corn Silage	Acres	62.76	75.0
Alfalfa	Acres	0	0
Purchased Corn	tons	55.97	102.35
Purchased Hay	tons	187.50	182.76
Expected Net Returns	$000s	63.8	53.3

expected nitrogen available from manure. Hence, expected total nitrogen application per acre is 271.33 lbs., of which 117.53 lbs. are in excess of anticipated crop needs. Expected net returns are about 20% less than obtained in the risk-neutral farm.

The nutrient management practices in the safety-first solutions are much more characteristic of Lancaster Co. farming practices than the expected profit maximizing solution. It is worth noting here that in general, safety-first behavior solution is not the only plausible explanation of increased fertilizer use *vis-a-vis* expected profit maximization. For example, the analysis by Pope and Kramer implies that, other things being equal, a risk-averse expected utility maximizing farmer will apply less or more fertilizer relative to a risk-neutral farmer depending on whether the farmer perceives it to be risk increasing or decreasing. The corn grain and silage response functions reported above were estimated using weighted least squares after positive testing for heteroskedasticity in the form of the error variance increasing with the level of nitrogen applied. This would suggest that increased nitrogen use increases yield risk. Thus, an expected utility maximizer would use less than an expected profit maximizer. The safety-first, chance-constrained structure, therefore, generates results that appear more consistent with observed behavior in the study area than a risk-averse expected utility maximization structure.

Policy Results

Surface and groundwater quality problems associated with agricultural production in the Chesapeake Bay region, including Lancaster Co., Pennsylvania, are viewed in large part as a consequence of application of manure and purchased fertilizer in excess of crop requirements. Accordingly, a key objective of environmental planners is to reduce or eliminate applications in excess of crop requirements (Swartz). If farmers subjective expectations of crop response to nitrogen application and the nitrogen content of manure correspond to those used by the relevant planners to define excess applications, then the expected profit-maximizing farm plan presented above is consistent with policy goals pertaining to nitrogen application rates while the safety-first plan is not. This clearly indicates that an understanding that farm behavior objectives and perceptions is important to explaining the problem of excess nutrient application.

Several policy approaches exist for reducing the

Table 2. Optimal Expected Profit Maximizing and Safety-First Base Solution Nitrogen Requirements and Applications per Acre

	Expected Profit Maximizing	Safety-First
Required Nitrogen per acre	167.0 lbs.	154.20 lbs.
Applied Nitrogen per acre		
from manure	148.52 lbs.	142.81 lbs.
from commercial nitrogen	18.43 lbs.	128.52 lbs.
Total application	167.0 lbs.	271.33 lbs.
Excess application over requirements	0	117.53 lbs.

excess nitrogen applications. One would be simply to mandate a reduction. A second approach and the centerpiece of state level policy in Pennsylvania is the use of moral suasion combined with information and education (I & E) programs to promote voluntary improvements in animal waste management and fertilization practices (Swartz). A third approach that is receiving attention is limiting animal densities on farms. This approach is of interest to some local planners concerned with protecting the quality of local ground and surface drinking water supplies. A fourth approach, which has long received attention by economists as a means of reducing a socially undesirable activity, is the use of negative economic incentives. The economically preferred base for such incentives would be nutrient losses to the environment but the stochastic nature of the losses and monitoring problems make this base infeasible (Bohm and Russell; Griffin and Bromley; Shortle and Dunn). Alternatively, incentives can be related to the application of nutrients. The analysis examines the farm-level effects of variants of each of these approaches. Policy approaches other than the ones examined in this study, of course, are conceivable. As with the policy approaches examined in this study, the response of individual farmers must be included in any assessment of the effectiveness of policy impacts.

I & E programs aimed at reducing nutrient application rates in Pennsylvania have two basic thrusts. One is to promote soil testing, under the hypothesis that many farmers systematically underestimated yield response to nitrogen. The second is to provide farmers with information about the value of manure as a fertilizer and soil conditioner, under the hypothesis that many farmers systematically underestimate the nutrient content of manure. Assessing the potential gains from the I & E approaches aimed at changing farmers' expectations is impossible without substantial prior knowledge of farmers' actual expectations, the actual biases of farmers' expectations *vis-a-vis* those used by public planners to define excess applications, their willingness to change their behavior in response to educational activities, and so on. Nevertheless, some useful inferences can be drawn.

The structure of the farm model is such that spread-preserving increases in the expected nitrogen content of manure and/or the expected yield derived from a given nutrient application rate would reduce the excess applications by the safety-first producer. The same adjustments would lead to reduced fertilizer purchases by the expected profit maximizing producer and presumably also a reduction in excess applications since the farmer's previous expectation would presumably be faulty. Alternatively, mean-preserving decreases in the spreads of the stochastic variables would reduce the excess applications of the safety-first farmer but not the expected profit maximizer. Hence, I & E programs could be beneficial under the behavior assumptions considered in this study if (1) farmers subjective expectations were biased *vis-a-vis* those of the relevant public planner, and (2) the programs increase farmers' subjective means and/or reduce their subjective dispersions. Under alternative assumptions, the changes in dispersion could, however, be counterproductive. For example, a decrease in the subjective dispersion of yield response could lead to increased nitrogen usage by a risk-averse expected utility maximizer.

To illustrate the possible effect of a mean-preserving decrease in spread assuming safety-first behavior, consider an increase in the coefficient of variation of nitrogen from 0.25 to 0.5. This in effect reduces the variability (uncertainty) by 75%. The results of such a reduction appear in the last pair of columns of table 3. The 75% reduction in uncertainty generated a 50% reduction in excess nitrogen applications, relative to the safety-first base plan. Of course, it is important to again emphasize that whether such a reduction could be gained in practice will depend upon farmers perceptions, about which little is now known, the responsiveness of their perceptions to I & E programs, and their behavioral objectives.

Consistent with the goals of the Chesapeake Bay Agreement, a minimum of 40% reduction of excess nitrogen application is used for illustrative purposes as a policy target for comparing alternatives to moral suasion combined with information and education.[1] Farmers' and public planners' subjective perceptions are assumed to correspond to the objective data used to specify the farm model.

To examine a mandated 40% reduction in excess applications, the representative farm model was solved explicitly limiting the excess nitrogen to 60% of the base safety-first scenario levels. The results are presented in table 3. Since the expected profit maximizing base solution generates zero excess nitrogen, the mandated reduction is not considered for that case. Cow numbers, manure spread on cropland, the expected manure nitrogen, and purchased nitrogen in the safety-first plan all fall essentially by one-half relative to the base scenario. The farm income reduction totals almost $5,300,

[1] The Chesapeake Bay Agreement commits Maryland, Pennsylvania, Virginia, and Washington, D.C. in cooperation with the EPA to the restoration of the Chesapeake Bay. A key provision of the agreement is a 40% reduction in nutrient loading by the year 2,000. Although the Bay goal does not imply individual farm goals, it does provide starting point for analysis.

Table 3. Optimal Farm Plans for the Excess Application, Restricted Animal Density and Information and Education Policy Options

Activities	Units	Restricted Excess Application		Restricted Animal Densities		Information and Education	
		Expected Profit Maximization	Safety-First	Expected Profit Maximization	Safety-First	Expected Profit Maximization	Safety-First
Dairy Stock	AU	129.0	75.43	75.0	75.0	129.0	125.75
Manure Spread on Cropland	tons	1,998.0	1,168.27	1,161.63	1,161.63	1,998.0	1,947.71
Expected Manure Nitrogen	cwt	109.89	64.25	63.89	63.89	109.89	107.12
Purchased Nitrogen	cwt	15.36	46.21	61.36	45.67	15.36	52.50
Expected Nitrogen Excess	cwt	0	52.87	0	52.51	0	44.05
Corn Grain	acres	0	1.36	38.51	1.36	12.24	0
Corn Silage	acres	12.24	43.77	36.49	43.47	62.76	75
Alfalfa	acres	62.76	29.87	0	29.87	0	0
Purchased Corn	tons	55.97	57.43	0	57.15	55.97	102.36
Purchased Hay	tons	187.50	0	109.01	0	187.50	182.78
Expected Net Returns	$000s	63.8	48.0	55.7	47.7	63.8	54.4

Table 4. Optimal Farm Plans for the 10, 50, and 100% Tax on Commercial Fertilizer

		10% Tax		50% Tax		100% Tax	
Activities	Units	Expected Profit Maximization	Safety-First	Expected Profit Maximization	Safety-First	Expected Profit Maximization	Safety-First
Dairy Stock	AU	129.0	125.74	129.0	125.44	129.0	125.0
Manure Spread on Cropland	tons	1,998.0	1,947.54	1,998.0	1,942.83	1,998.0	1,936.17
Expected Manure Nitrogen	cwt	109.89	107.11	109.89	106.85	109.89	106.49
Purchased Nitrogen	cwt	15.36	96.39	0	92.56	0	88.70
Expected Nitrogen Excess	cwt	0	88.15	0	87.93	0	87.62
Corn Grain	acres	12.24	0	11.43	0	11.43	0
Corn Silage	acres	62.76	75.0	63.57	75.0	63.57	75.0
Alfalfa	acres	0	0	0	0	0	0
Purchased Corn	tons	155.96	102.35	59.18	102.10	59.18	101.75
Purchased Hay	tons	187.50	182.76	187.50	182.32	187.50	181.70
Expected Net Returns	$000s	63.7	53.3	63.7	52.0	63.7	50.9

despite a shift in cropping pattern and a reduction in purchased corn grain and hay. This farm provides almost all of its own feed.

The third policy approach considered is a limit on animal densities. The results are also presented in table 3. A density of 1.00 AU per acre was determined to effect a reduction in excess nitrogen of approximately 40% relative to the safety-first base scenario, down from 1.68 AU per acre. While the optimal farm plan for the expected profit maximizing farmer generated zero excess nitrogen, this restriction was also imposed on the expected profit maximizing producer, since such a policy would affect all farmers, regardless of behavior. The restriction causes a shift in cropping pattern for the expected profit maximizing producer, and a substantial increase in purchased nitrogen over the base scenario. The income reduction is over $8,000. The shadow-price of the constraint limiting cow numbers is almost $275 per head. For the safety-first producer, total manure and purchased nitrogen fall substantially relative to the safety-first base plan. The income reduction due to the restriction is nearly $5,550. The shadow-price on the herd size constraint is over $228 per head.

The fourth general option considered here is the use of fiscal incentives. Three types of taxes are examined. The first is a tax on commercial nitrogen purchases. Alternatively, total nitrogen application and the excess nitrogen application could be taxed to reduce the excess applications.

Although taxes on nitrogen fertilizer purchases are much discussed, no actual proposals upon which to base a rate structure exist. For the purpose of this study, nitrogen fertilizer purchases were taxed at 10, 50, and 100% of the purchase price, and the results appear in table 4. These tax rates had only a minimal effect on the safety-first farmer's purchase of commercial fertilizer and the level of excess applications, although the expected profit maximizing producer ceased the purchase of nitrogen altogether. The levels and mix of activities remain essentially unchanged from the base scenarios with net returns reduced by the amount of the tax.

Total nitrogen applications were also taxed at 10, 50, and 100% of the price of commercial nitrogen fertilizer. The 10% tax had little effect on the optimal farm plans of either the expected profit maximizing or safety-first procedures relative to the no-tax situation (see table 5). Although not reported in table 5, the 50% tax rate had similar results. The 100% tax rate did cause a slight drop in excess nitrogen applications for the safety-first producer. This decrease, however, is not commensurate with the decline in purchased nitrogen. Animal numbers are reduced, leading to less expected manure nitrogen. Less commercial fertilizer is purchased. Yet the excess remains high in this safety-first solution because over seven acres were shifted from corn silage to alfalfa, a legume that does not require nitrogen applications. The remaining acreage, devoted to silage, was fertilized heavily. So while total nitrogen use decreased significantly, over 40 cwt. relative to the safety-first base scenario, the nitrogen applications still exceeded anticipated crop requirements by over 78 cwt., a drop of only 9.72 cwt. The income reduction *vis-a-vis* the base scenario totals over $10,000.

A third possible tax approach would be to tax the excess nitrogen applications. An appealing feature of this incentive relative to the taxes on purchased and total nitrogen is that only farmers fertilizing in excess of crop requirements would pay the tax. This approach has been implemented in the Peel Region of the Netherlands (Van Boheemen). Farmers in this region must keep detailed records of the nutrient flows onto and off the farm.

Table 5. Optimal Farm Plans for the 10 and 100% Tax on Total Nitrogen Applications

		10% Tax		100% Tax	
Activities	Units	Expected Profit Maximization	Safety-First	Expected Profit Maximization	Safety-First
Dairy Stock	AU	129.0	125.65	129.0	113.18
Manure Spread on Cropland	tons	1,998.0	1,947.54	1,998.0	1,732.49
Expected Manure Nitrogen	cwt.	109.89	107.07	109.89	94.28
Purchased Nitrogen	cwt.	15.36	96.39	0	66.86
Expected Nitrogen Excess	cwt.	0	88.11	0	78.39
Corn Grain	acres	12.24	0	11.43	0
Corn Silage	acres	62.76	75.0	63.57	67.80
Alfalfa	acres	0	0	0	7.20
Purchased Corn	tons	55.96	102.30	59.18	91.05
Purchased Hay	tons	187.50	182.60	187.50	136.24
Expected Net Returns	$000s	63.4	53.3	60.8	43.2

At the end of the year, the farmer, using a schedule similar to a tax return, computes the total nutrients applied to the ground. The total loading per hectare is compared to a standard. A tax rate is applied to all loadings over the standard.[2]

The shadow price on the constraint limiting the nitrogen excess in table 1 can be used to infer the tax that would provide a 40% reduction in the excess. The shadow price is $189.57/cwt. Since the optimal farm plan with a tax on the nitrogen excess imposed at a rate of $189.57/cwt. will be the same as the optimal plan solution with the constraint requiring a 40% reduction of the excess, the farm plan for the tax can be identified in table 1. The income reduction due to the tax is equivalent to the income reduction due to the constraint plus the tax payments, about $22 thousand. Although a substantial penalty, it is clearly less than the penalties that would result from the taxes on purchased or total nitrogen that would yield a 40% reduction in excess applications.

Summary and Conclusions

This study has examined the problem of reducing nutrient application rates for water quality protection. The main purpose is to demonstrate the importance of behavioral objectives for the design of economically sound policies. Different policies were examined as to their effects on farm-level decisions under two different behavioral assumptions: risk-neutral expected profit maximizing behavior and risk-averse safety-first behavior. The policies involving limits and taxes on excess nitrogen applications have no impact on the profit-maximizing farm plan if the subjective expectations underlying the plan correspond to the public expectations used to define excess applications. Such a correspondence is assumed in the evaluation of all policies except the information and education programs. Because the distributional parameters used to specify this constraint are objective, the discussion of the effects of the information and education programs is non-numeric with the exception of the consideration of a mean-preserving reduction in the dispersion of manure-nitrogen content.

Substantial differences are found between the response of the expected profit-maximizing and safety-first plans to the various policies. This statement is true by assumption, but equally relevant, for the policies involving taxes or limits on excess nitrogen applications and information and education programs as modeled in this study. There are significant differences in the other cases as well. For example the taxes considered on total nitrogen and nitrogen purchases have a substantial impact on fertilization levels in the profit-maximizing plan but a small impact on fertilization in the safety-first plan. Correspondingly, these taxes are much more burdensome in the safety-first plan than in the profit maximizing plan.

In addition to substantial differences between the effects of the policies on fertilization decisions and income between the two plans, there are substantial variations within the plans. Important here is the indication that some policies may severely reduce income without having much impact on excess applications, while others may be much more effective without nearly the cost in terms of forgone farm income. This is especially true when taxes are compared to regulations but is also a consideration when comparing alternative regulations and taxes. For example, mandated reductions in excess application cost less and accomplished more than limiting animal densities. Clearly, variations in cost-effectiveness of alternative policies is to be expected generally but the issue that becomes apparent here is that these variations may be strongly influenced by behavioral considerations. For example, under safety-first behavior the attractiveness (cost-effectiveness) of mandated reductions in excess applications increases in comparison to restricting animal densities as the degree of risk-aversion diminishes, all other things being equal.

One possible interpretation of these results showing sensitivity of policy impacts to alternative behavioral frameworks is that greater information about farmer behavior is needed to design economically sound programs. Alternatively, recognizing that there are limits to what can be learned, another possible interpretation is that analysts can contribute to the design of good control programs by identifying and evaluating approaches with impacts and compliance costs that are relatively insensitive to alternative individual behaviors and perceptions. Of the approaches considered here, the limit on excess applications is relatively appealing in that it is selective and allows farmers' to minimize their costs of reducing excess applications. Of course, this statement is not intended to be a recommendation since transactions costs, the spectrum of policy alternatives, and the appropriateness of agronomic excess applications as an environmental performance indicator have not been examined.

[2] Currently, the nutrient of interest in the Peel region is phosphorus, not nitrogen. The public officials have instituted a phased-in approach by forcing farmers to keep track of records and filling out the forms now; however, the applicable standard is set so high as to not affect even the most flagrant excesses. Over the next several years, however, the standard is to be reduced gradually until the desired standard is reached. The tax rate remains the same, the standard is changed.

References

Abdalla, Charles W., Douglas B. Beegle, and William T. McSweeny. "Policy Choices: Animal Agriculture and Groundwater Control." *Farm Economics*. Penn State Cooperative Extension, University Park, Pennsylvania, March/April 1987.

Bohm, P. and C. S. Russell. Comparative Analysis of Alternative Policy Instruments. Chapt. 10 in A. V. Kneese and J. W. Sweeny, et.s. *Handbook of Natural Resource and Energy Economics*. Amsterdam: North-Holland, 1985.

Charnes, A. and W. Cooper. "Chance Constrained Programming." *Management Science*. 6(1959):73–79.

Crowder, Bradley M. and C. Edwin Young. *Managing Farm Nutrients: Tradeoffs for Surface- and Ground-Water Quality*. Agricultural Economic Report Number 583 United States Department of Agriculture, Economic Research Service, Washington, D.C., January 1988.

de Janvry, A. "Optimal Levels of Fertilization under Risk: The Potential for Corn and Wheat Fertilization under Alternative Price Policies in Agriculture." *American Journal of Agricultural Economics* 54(1972):1–10.

Fox, Richard H. and William P. Piekielek. *Response of Corn to Nitrogen Fertilizer and the Prediction of Soil Nitrogen Availability with Chemical Tests in Pennsylvania*. Pennsylvania Agricultural Experiment Station Bulletin No. 843, The Pennsylvania State University, University Park, April 1983.

Hazell, Peter B. R. and Roger D. Norton. Mathematical Programming Analysis for Economic Analysis in Agriculture. New York: Macmillan Publishers, 1986.

House, Robert, Clayton Ogg, Kenneth Clayton, and James Johnson. *USDA Conservation Incentives Study*. Staff Report No. AGEB20104, USDA, ERS, NED, Washington, D.C., January 1982.

Judge, George R., William E. Griffith, R. Carter Hill, and Tsoung-Chao Lee. *The Theory and Practice of Econometrics*. John Wiley and Sons: New York, 1980.

Kashmanian, Richard, Donna Downing, John Jaksch and Mahesh Podar. "A Cost Effective Approach to Managing Nonpoint/Point Source Phosphorus Loadings: A Case Study of the Chesapeake Bay." Paper presented at the Eighth Biennial International Estuarine Research Federation Conference, Durham, New Hampshire, 1985.

Katoka, S. "A Stochastic Programming Model." *Econometrica*. 31(1963):181–196.

Lin, William, G. W. Dean, and C. V. Moore. "An Empirical Comparison of Utility versus Profit Maximization." *American Journal of Agricultural Economics*. 56(1974):497–508.

Lindley, J. A. and D. W. Johnson. *Quality of Livestock Manure in North Dakota*. North Dakota Research Report 107, North Dakota Agricultural Experiment Station, Fargo, North Dakota, November 1987.

Murtaugh, Bruce A. and Michael A. Saunders. *MINOS 5.0 USER'S GUIDE*. Systems Optimization Laboratory SOL 83-20, Department of Operations Research, Stanford University, Stanford, California, December 1983.

Paris, Quirino and Christopher D. Easter. "A Programming Model with Stochastic Technology and Prices: The Case of Australian Agriculture." *American Journal of Agricultural Economics* 67(1985):120–129.

Pope, Roulon D. and Randall A. Kramer. "Production Uncertainty and Factor Demand for the Competitive Firm." *Southern Economic Journal*. 46(1979):489–501.

Roy, A. D. "Safety-First and Holding of Assets." *Econometrica*. 20(1952):431–449.

Shackle, G. L. S. *Decision, Order, and Time in Human Affairs*. London: Cambridge University Press, 1969.

Shortle, James S. and James W. Dunn. The Relative Efficiency of Alternative Agricultural Source Pollution Control Policies. *American Journal of Agricultural Economics*. 68(1986):668–677.

Swartz, Paul O. "Nutrients: The Missing Link." Presented paper at the Costal Society Meeting, New Orleans, October 13, 1986.

Telser, L. G. "Safety-First and Hedging." *Review of Economic Studies*. 23(1955):1–16.

U.S. Environmental Protection Agency. *Chesapeake Bay Program—A Framework for Action*. Draft manuscript, Washington, D.C., 1983.

———. Office of Water Program Operations. *Report to Congress: Nonpoint Pollution in the U.S.* January 1984.

Van Boheemen, P. J. M. "Extent, Effects, and Tackling of a Regional Manure Surplus: A Case Study for a Dutch Region." in *Animal Manure on Grassland and Fodder Crops. Fertilizer or Waste*, H. G. Van Der Meer, R. J. Urwin, T. A. Van Dijk, and G. C. Ennuk, Eds. Proceedings of an international symposium, Waggeningen, The Netherlands 31 Aug–3 Sept. 1987, Martinus Nijhoff Publishers, Dordreet 1987.

Young, C. Edwin, Jeffrey A. Alwang, and Bradley M. Crowder. *Alternatives for Dairy Manure Management*. Staff Report AGES860442, USDA, ERA, NRED, Washington, D.C., July 1986.

Young, C. E. and R. S. Magelby. "Agricultural Pollution Control Implications From The RCWP Program." *Water Resources Bulletin* 23(1987):701–707.