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Risk and Site Factors Affecting Potential Nitrogen Delivery in the Virginia Coastal Plain

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ABSTRACT

The effects of cropland slope, distance to surface water, farmers' risk attitudes, and farmers' nitrogen (N) fertilizer applications on potential N delivery to streams and costs of reducing N delivery were evaluated for a representative Virginia peanut-cotton farm. Target MOTAD and generalized stochastic dominance were used to select preferred plans for different levels of risk aversion. Costs of reducing N delivery were lower on farms where fields were located close to surface water, where N was overapplied relative to extension fertilizer recommendations, and where the operator was risk averse. Cropland slope had less effect on cost of reducing N delivery relative to other factors.

Key Words: *cost, nonpoint source pollution, risk programming, simulation, stochastic dominance, targeting.*

There is increasing public concern about nonpoint source (NPS) pollution control. Contaminated water can damage human health and that of other species and there are, of course, many uses for which clean water has no substitute. Numerous Federal and state pollution-control policies have attempted to control NPS pollution. The Coastal Zone Management Act Reauthorization Amendments require states with approved coastal zone management programs to develop NPS pollution-control plans for coastal zone areas including agriculture (Ribaudo, Horan, and Smith). States are now required to develop Total Maximum Daily Loads (TMDLs) for waters where the applicable water quality standard has not been achieved (U.S. Environmental Protection Agency, 1991). NPS pollution control policies affect agriculture, a major contributor to NPS pollution (U.S. Environmental Protection Agency, 1994).

Pollution control is costly to the public and/or private firms and individuals. State and federal funds for pollution control assistance are limited. Costs incurred by firms may reduce their competitiveness and/or raise consumer costs. Because agricultural sources of NPS pollution vary in pollution potential and control costs, total control costs can be reduced by targeting reductions at farms with low control costs per unit of pollutant (National Research Council; VanVuuren, Giraldez, and Stonehouse; Carpentier, Bosch, and Batie; VanDyke, Bosch, and Pease; and Randhir and Lee). However, policymakers and

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program administrators often lack information on how practices can be targeted to reduce costs. As a result, costs may exceed levels necessary to achieve pollution-control goals.

Cost-effective targeting of NPS pollution reduction requires methods for identifying where low-cost opportunities exist (Braden *et al.*). Pollution runoff can be reduced by lowering soluble runoff and erosion because much of pollutant runoff is attached to eroded sediment. Erosion can be lowered with cover crops, using reduced tillage methods, or by shifting to crops which are less tillage intensive. Methods of controlling soluble runoff include reducing nutrient application rates, timing nutrient applications to match crop needs, and growing winter cover crops to hold nutrients in the soil (National Research Council). Costs and effectiveness of such measures depend on soil type, slope, or distance to surface water where they are used and their potential to intercept pollutants from upslope sites (Braden *et al.*). Length, slope, and cover of the flowpath from edge of field to surface water affect the delivery ratio of displaced sediment and its adsorbed pollutants, including nitrogen (N) and phosphorus (P) (Shanholtz and Zhang).

Farmers' adoption of pollution-control practices depends on the perceived costs of such practices. If practices make either returns or costs more variable, the increased risk is viewed as an additional cost (Feinerman, Choi, and Johnson). Farmers' N applications depend on their assessments of the effects of N on net returns risk. Studies by Babcock, Chalfant, and Collender; Rosegrant and Roumasset; and Lambert concluded that N is risk increasing. However, these studies were based on experimental yields. Sri Ramaratnam, *et al.* compared farmers' perceptions of yield risks and N applications with experimental data and found that farmers viewed N as risk reducing while experimental results showed it to be risk increasing. Possibly risk-averse farmers may apply more N than needed to maximize expected profits in order to reduce risk. When weather or soil N levels are uncertain, it may be optimal to apply more N than needed to maximize profits based on the average yield function (Babcock), which implies that risk also increases N applications by risk-neutral producers.

Some farmers may overapply N because they lack information about crop nutrient requirements or the availability of crop nutrients from sources including legume carryover and manure (Norris and Shabman). Bosch *et al.* found that about 25 percent of a sample of Eastern Virginia crop farmers overapplied N by 13 to 38 percent compared to Virginia Cooperative Extension Service recommendations. VanDyke *et al.* documented fertilizer cost savings on four case Virginia farms which adopted nutrient management plans. Farmers must be supplied with site- and time-specific information about crop nutrient requirements in order to reduce unnecessary N applications. But the benefits of information should exceed its cost in order to increase profit and reduce environmental damages (Fuglie and Bosch). More information is needed on how socio-economic and site physical factors affect the costs of reducing N pollution. This information can be used by policy makers to target N reduction efforts.

The objectives of this study are to identify major factors that affect delivery of N to streams from peanut-cotton farms in Virginia and to evaluate the costs of reducing N deliveries with respect to each of the factors. A representative farm was used to estimate N delivery and control costs. The effects of farmers' prior N application practices, cropland slope, distances from cropland to the nearest stream, and farmers' risk attitudes on costs of reducing N delivery were evaluated. While previous studies have identified farm costs of controlling pollution, less attention has been paid to how farmer characteristics and physical attributes affect those costs.

The analysis was applied to a representative Virginia peanut-cotton farm located in the Albemarle-Pamlico watershed, which covers southeast Virginia and northeast North Carolina. In saline coastal watersheds, either N or P pollution may be the major contributing factor to algae growth depending on time of the year and location of pollution (Fisher and Butt). Almost 80 percent of the nutrients entering receiving waters in the watershed comes from NPS pollution and 75 percent of the NPS pollution comes from agricultural activities (North Carolina Division of Environmental Management; Hall and Howett). Because of concern with nutrient pollution in this watershed, this study focuses on N deliveries. However, the procedures are applicable to other pollutants as well.

This study was based on a performance standard of reduced N delivery. Performance standards are infrequently used for NPS pollution control because of the difficulty of monitoring NPS loadings and enforcing reductions (Abler and Shortle). However, information from this study can also be used for other policy instruments such as nutrient trading.

Conceptual Framework

Farm decisions were modeled using a Target-MOTAD model (Tauer). The farmer maximizes expected net income as long as the expected shortfall (negative deviation) from the target income does not exceed a specified level. The model is

$$(1)\quad \text{maximize } E(z) = \sum_{j=1}^{n} c_j x_j$$

subject to

$$(2)\quad \sum_{j=1}^{n} a_{kj} x_j \leq b_k, \qquad k = 1, \ldots, m$$

$$(3)\quad \sum_{j=1}^{n} d_j x_j \leq D$$

$$(4)\quad T - \sum_{j=1}^{n} c_{rj} x_j - y_r \leq 0, \qquad r = 1, \ldots, s$$

$$(5)\quad \sum_{r=1}^{s} p_r y_r = \lambda, \qquad \lambda = M \rightarrow 0$$

where c_j is expected return of activity *j*, x_j is level of activity *j*, a_{kj} is technical requirement of activity *j* for resource *k*, b_k is level of resource or constraint *k*, *m* is the number of resource constraints, d_j refers to nitrogen delivery from activity *x*, *D* is the total allowable nitrogen delivery from the farm, *T* is target income, c_{rj} is return of activity *j* for state of nature *r*, y_r is return deviation below *T* for state of nature *r*, *s* is number of states of nature or observations, p_r is the probability that state of nature *r* occurs, λ is a constant parameterized from *M* to 0, and *M* is a large number. Inequalities in (2) reflect technical constraints while (3) refers to a nitrogen delivery constraint. By varying the value of λ, the model traces out a set of E-λ points corresponding to efficient farm plans by second-degree stochastic dominance (SSD efficient) (Tauer). Teague, Bernardo, and Mapp used Target MOTAD to evaluate the effects of stochastic constraints on nitrate and pesticide loadings on expected farm income. We focused on effects of income risk and risk aversion on the costs of complying with constraints on N delivery (*D*).

The model was used to generate a set of E-λ efficient points with *D* set at a large number so there was no constraint on N delivery. A risk-aversion interval was selected and generalized stochastic dominance was used to find the points that are SSD efficient for that interval (Meyer; Goh *et al.*). Then *D* was lowered so the farm was required to reduce total N delivery relative to the estimated N delivery in the baseline. Target MOTAD was used again to generate the efficient frontier and generalized stochastic dominance was used to select the preferred farm plan for the selected risk-aversion interval. Generalized stochastic dominance was used to compare the preferred plan without the N delivery constraint to the preferred plan with the N delivery constraint. This comparison resulted in an estimate of the lower bound of the risk-adjusted cost of reducing N delivery. The risk-adjusted cost is the amount by which net returns with no reduction in N delivery can be lowered before they no longer dominate net returns obtained after the N reduction (Goh *et al.*). In the case of risk neutrality, the preferred strategies with and without the N delivery constraint are those which maximize expected net returns. The cost of N delivery reduction is the difference in expected net returns between the two strategies.

The effects of N delivery constraints were evaluated by setting *D* at 7500 pounds below the baseline for each farm. A 7500-pound amount was selected because it represents a significant (20–26 percent) yet realistic reduction from the baseline for each farm situation based on nutrient reduction goals set in other watersheds. For example, the Chesapeake Bay Agreement set a goal of 40-percent reduction in N deliveries to the Chesapeake Bay (Chesapeake Bay Program, 1983, 2000). Sensitivity of N reduction costs to level of reduction is also reported.

Empirical Model

The Representative Farm

The 1992 Area Studies Survey[1] collected information on farm characteristics and practices related to water quality on randomly sampled fields on 980 farms in the watershed. Sites were randomly sampled from the National Resource Inventory (NRI) (USDA, Soil Conservation Service, and Statistical Laboratory of Iowa State University) and farmers of the sites interviewed. Of 980 farms, 184 were categorized as "other crop farms" on which peanut enterprises account for a large share of farm income. This study focused on such farms which typically grow peanuts, cotton, soybeans, corn, and wheat, which accounted for 67 percent of crop acres in the watershed (USDA, Economic Research Service). Peanuts and cotton are high-value crops that are tillage- and chemical-intensive, which increases potential pollution runoff.

A representative peanut-cotton farm was developed based on conditions in the rural City of Suffolk, a major peanut-producing area in Virginia. According to the Area Studies Survey, the single largest portion of the study area is classified as Emporia soil, which makes up 22.6 percent of soil on 107 of the 184 Virginia peanut farms having soil data available. Emporia soil type falls within the Eunola-Kenansville-Suffolk association,[2] which makes up 41 percent of the area. It was assumed that Emporia is the only soil type for the representative farm.

The representative farm has 750 acres of cropland (Sturt, 1997b), which is close to the Area Study Survey average of 723 acres for peanut farms in that area. Of the 750 acres, 550 acres are rented and 200 acres are owned (Sturt, 1997b). The land rental rate is $70 per acre including rental fee for peanut quota. Peanut quota was set at 590,000 pounds, the average value of the Area Study Survey sampled peanut farms in Virginia. Commodity program participation was assumed for corn, cotton, and winter wheat in order to estimate the contribution of program payments to the income target—$4100 for cotton; $3350 for corn; and $1570 for wheat. Supplemental program payments made to farmers in 1998 and 1999 were not included and corn, cotton, and wheat base acreages were 180, 150, and 90, respectively. Other program considerations such as cross compliance were not included.

One full-time laborer is hired at $22,500 per year. The farm owner and full-time laborer can provide 1250, 1000, 1250, and 1000 hours for spring, summer, fall, and winter, respectively. Unlimited part-time labor can be hired at $6 per hour. The farm has a land debt of $150,000 at 10-percent interest on a 15-year term with an annual payment of $19,725. Social security taxes, family living expenses, and income taxes total $40,000 per year. These costs summed together with annual land rent, real estate tax and insurance, and payment for full-time labor, yield a total of $112,500, which is the farmer's income target. The annual machinery interest and principal payment are not included since they were incorporated into variable expenses.

Five conventional rotations (numbered 1 to 5) and six conservation rotations (numbered 6 to 11) are listed in Table 1 with means and standard deviations of their per-acre net returns. These rotations were developed by consulting research and extension specialists and a farmer in the study area and publications (Sturt, 1997a; North Carolina Cooperative Extension Service). The conservation rotations involved reduced tillage on cotton, cover crops following cotton, peanuts, or corn, and idling land. Idle land was assumed to be planted to a cover crop with no N applied, which reduced N loss potential but also eliminated crop revenue. Cover crops pro-

[1] The Area Studies Survey was a collaborative effort of the USDA Economic Research Service (ERS), National Agricultural Statistics Service, Soil Conservation Service (now Natural Resource Conservation Service (NRCS)), and U.S. Department of Interior's Geological Survey.

[2] A *soil association* is defined as a group of soils geographically associated in a characteristic repeating pattern and defined and delineated as a single map unit (USDA-SCS).

Table 1. Mean (Standard Deviation) of Crop Rotation Per-Acre Net Returns[a]

Rotation number and name with description	Net Returns Mean/Standard Deviation by Slope					
	N Applied at Recommended Rate			N Applied 20% Above Recommended Rate		
	1% Slope	3% Slope	5% Slope	1% Slope	3% Slope	5% Slope
1. CTC-CTP (conventional-till cotton, conventional-till peanut)	238 (127)	231 (128)	227 (127)	236 (127)	230 (128)	226 (128)
2. CTP-NTC (conventional-till peanut, no-till corn)	135 (67)	132 (69)	130 (69)	132 (67)	129 (69)	127 (69)
3. CTP-MTW-NTSB-CTC (conventional-till peanut, minimum-till wheat, no-till soybean, conventional-till cotton)	218 (96)	214 (96)	210 (97)	216 (96)	212 (97)	208 (97)
4. MTW-NTSB-NTC-CTP (minimum-till wheat, no-till soybean, no-till corn, conventional-till peanut)	157 (65)	153 (66)	150 (68)	154 (65)	150 (67)	147 (68)
5. MTW-NTSB-CTC (minimum-till wheat, no-till soybean, conventional-till cotton)	194 (93)	191 (95)	181 (95)	193 (96)	190 (97)	179 (97)
6. MTW-NTSB-STCC (minimum-till wheat, no-till soybean, strip-till cotton with cover)	188 (92)	183 (94)	175 (92)	185 (92)	180 (95)	172 (93)
7. CTCC-CTPC (conventional-till cotton with cover, conventional-till peanut with cover)	203 (126)	196 (127)	192 (126)	201 (127)	195 (128)	191 (127)
8. STCC-CTPC (strip-till cotton with cover, conventional-till peanut with cover)	216 (126)	209 (127)	205 (126)	215 (127)	208 (128)	204 (126)
9. NTCC-CTPC (no-till corn with cover, conventional-till peanut with cover)	99 (66)	96 (68)	94 (69)	96 (66)	93 (68)	91 (69)
10. CTPC-MTW-NTSB-STCC (conventional-till peanut with cover, minimum-till wheat, no-till soybean, strip-till cotton with cover)	204 (96)	198 (97)	195 (98)	202 (96)	196 (97)	192 (98)
11. IL (idle land in annual wheat cover)	−36 (0)	−36 (0)	−36 (0)	−36 (0)	−36 (0)	−36 (0)

[a] Rotations 1 to 5 are conventional and rotations 6 to 11 are conservation rotations.

tect soil during the winter months, thereby reducing sediment and nutrient runoff, and take up N during winter months, thereby reducing N leaching potential (Novotny and Olem). However, the costs of planting cover may exceed the value of nutrients and sediment saved. Strip-till cotton involves shallow tillage in rows where the seed is placed (one third or less of the total row area) with the remaining row left undisturbed. Total costs of strip-till are slightly less than conventional-till (Peng) as machinery costs are reduced but chemical costs are increased. Strip-till reduces loss of sediment and sediment-adsorbed N but soluble N runoff losses may increase because N is less likely to be incorporated into soil.

Crop Prices

The Food and Agricultural Policy Research Institute (FAPRI) forecast corn, cotton, wheat, and soybean prices for 1997–2002 were deflated to

1995 dollars and averaged to approximate expected crop prices. The deflated average prices are $0.58 per pound (cotton), $2.35 per bushel (corn), $2.96 per bushel (wheat), and $5.32 per bushel (soybeans). The peanut quota price was fixed at a nominal value of $610/ton from 1996 to 2002 as set by the 1995 Farm Bill (FAIR). Average price for additional peanut was set at $375/ton. The deflated average prices are $0.25 per pound for quota peanut and $0.17 per pound for additional peanut.

The variability of crop prices except for quota peanut was based on historical prices (inflated to 1995 dollars) from 1986 to 1995 for Southeastern Virginia. For example, the 1986 cotton price was 10 percent below the mean price for 1986–1995; therefore the FAPRI forecast price was lowered by 10 percent to $0.53 per pound. Additional peanut prices were assumed to vary in the same way as did soybean prices (Peng).

Crop Yields and N Runoff

Crop yields and N losses were simulated by the Erosion-Productivity Impact Calculator (EPIC) (Williams, Jones, and Dyke). EPIC is a crop growth and chemical transportation simulation program, which can estimate crop yields and chemical losses using weather, soil, and management data. Historical weather data for the City of Suffolk for 1986–1995 were used to simulate yields, and weather data from 1976 to 1995 were used to simulate N losses. Soil type, cropland slope, and management operations for the representative farm were entered into EPIC to obtain the simulated yield distributions as well as the expected N losses.

EPIC model settings were calibrated based on 1991–1995 peanut, cotton, soybean, corn, and wheat yield data from the Tidewater Agricultural Research and Extension Center in Suffolk, Virginia. Initial EPIC settings were reviewed by soil and crop production experts at Virginia Tech[3] to ensure that they reflected Virginia growing conditions. The EPIC model was run under the same weather, soil, and management conditions as used for the crop experiments at Suffolk. Where necessary, further adjustments in EPIC parameters were made until the average simulated yield for each crop was within 10 percent of the average actual yield (Peng). Because of lack of data it was not possible to evaluate EPIC estimates of N leaching and runoff. However, EPIC has been widely used to evaluate nutrient losses from cropping practices in the U.S., Europe, and Australia (Williams, Jones, and Dyke).

Net Returns

Expected crop net returns equal the expected crop price (the FAPRI projected price in 1995 dollars) times the average crop yield simulated by EPIC for 1986–1995 minus crop variable expenses (Sturt, 1997a). Variability of returns was incorporated by generating ten random per-acre net returns for each crop as shown in (4). The crop's generated prices and simulated yields for each year from 1986 to 1995 were multiplied to produce that year's gross revenue from which crop variable expenses were subtracted. The resulting empirical joint distribution preserved the observed dependency between weather conditions and prices from 1986–1995.

Physical and Socioeconomic Factors Affecting N Delivery

Slope

The farm's cropland by slope was based on data from the Area Studies Survey about the distribution of soil slopes for Virginia peanut-cotton growers reporting Emporia soil. Of the surveyed 22 sites with Emporia soil, nine sites (or 41 percent) are of slope less than 1 percent, 11 sites (50 percent) are between 1 and 5-percent slope, and 2 sites (9 percent) are more than 5-percent slope. One cropland slope scenario assumed that 300 acres, 375 acres, and 75 acres of cropland on the representative farm are of 1-percent, 3-percent, and 5-percent slope, respectively. A second, steeper cropland slope scenario assumed that 225 acres, 300

[3] Azenegashe Abaye, Wesley Adcock, and James Baker, Department of Crop and Soil Environmental Science, and Patrick Phipps, Department of Plant Pathology, Physiology, and Weed Science, Virginia Tech, Blacksburg, Virginia.

acres, and 225 acres of the farm's cropland are of 1-percent, 3-percent, and 5-percent slope, respectively.

Distance

N delivery to surface water was calculated as the sum of soluble N loss and N attached to eroded sediment which is delivered to surface water. Soluble N loss equaled the sum of mineral N loss in percolate, subsurface flow, and surface runoff. All soluble N losses were assumed to be delivered to the stream.[4] Only part of the eroded sediment and its adsorbed N reaches the stream based on the delivery ratio, DELIVRAT, (Shanholtz and Zhang):

(6) $DELIVRAT = e^{-WTDCOV * TOTDIST * SLOPEFN}$

where WTDCOV is the weighted average cover factor for the intervening land between the site and the nearest water body (Shanholtz and Zhang), TOTDIST is distance measured as hundreds of meters from the site to the nearest water body, and SLOPEFN represents a factor to account for slope of the flow path between the site and the stream. Thirty survey points from the NRI database for Suffolk, Virginia are less than 5240 feet away from surface water of which 15 points are within 650 feet of surface water while the other 15 are more than 700 feet (and less than 1400 feet). The delivery ratios were calculated for these two groups, called "close" to the stream and "far" from the stream, respectively. The calculated average delivery ratios are 0.535 for the farm close to the stream and 0.151 for the farm far from the stream.

Information

A survey by Bosch *et al.* in the Northern Neck region of Virginia found that 25 percent of sampled farmers overapplied N by 13 percent to 38 percent compared to extension recommendations. However, there was no survey evidence that higher N applications reflect risk averse behavior. Applications above recommendations may reflect farmers' lack of information about crop nutrient sources and requirements (Norris and Shabman).

In one N application scenario, it was assumed that N applications are based on VALUES (Simpson *et al.*), the Virginia Cooperative Extension Service recommendations. In a second scenario, N applications to corn, wheat, and cotton were 20 percent above VALUES recommendations. A total of 21 rotations are considered in this study, including those shown in Table 1 and the first 10 rotations in Table 1 with 20 percent over-application of N.

Risk Attitudes

Based on King and Oamek, three types of risk aversion were considered in this study: risk neutrality (absolute risk-aversion coefficient equal to 0), moderate risk aversion (absolute risk-aversion ranges from 0.00001 to 0.00005), and strong risk aversion (absolute risk-aversion ranges from 0.00005 to 0.0001). Generalized stochastic dominance was used to determine which farm plans from the Target-MOTAD frontier were preferred for the three levels of risk aversion. A computer program by Goh *et al.* was used to do pairwise stochastic dominance comparisons and calculate risk premiums associated with each absolute risk-aversion interval. The lower bound of the risk premiums was used to approximate the risk-adjusted cost of N reduction when a risk averter shifts from his baseline optimal plan to a plan with reduced N delivery. The lower bound of the risk premium is the amount by which the dominant distribution can be lowered before it no longer dominates (Goh *et al.*).

Results and Discussion

N Deliveries by Rotation, N Application, and Cropland Location

Total N deliveries were higher for fields located closer to the stream, with steeper slopes, where N is overapplied relative to recommendations, and for rotations with higher N ap-

[4] N in percolate may remain in groundwater aquifers for many years before reemerging as surface flow. Some N may remain in groundwater indefinitely. It was not possible to estimate what portion of N in percolate remains in the aquifer.

plications, especially rotations 3, 4, 5, 6, and 10 which include wheat (Table 2). However, the increases in deliveries depended on interrelationships between these factors. For example, while N deliveries were higher on fields with steeper slopes, the increases were greater on fields located close to water. Substituting less polluting rotations on steep land will work more effectively on farms located closer to water. While N deliveries were higher for fields where N was overapplied, the absolute increases depended on the crop rotation. Absolute increases were greatest for rotations which included wheat, a crop in which much of the applied N is top-dressed rather than incorporated and, therefore, more susceptible to runoff.

Conservation practices varied in effectiveness. Deliveries were reduced most by idling land. N delivery was reduced by four to seven pounds per acre with a winter cover crop. Reducing cotton tillage reduced N delivery by 0.3 to 1.5 pounds/acre with larger reductions on fields closer to streams where more sediment-adsorbed N reaches the stream.

Baseline Results for the Risk Neutral Farm

N overapplication caused the greatest increase in N delivery with increases of 16 to 18 percent compared to the farm which applied at recommended rates (Table 3). N deliveries were 10 to 15 percent higher on the farm located close to surface water. The steep-sloped farm had 0 to 3 percent higher deliveries than the flat farm with larger increases on the farm located close to water. These findings suggest that the greatest opportunities for cost-effective N delivery reductions are on farms where N is currently overapplied, particularly if such farms are located near surface water.

The optimal mix of crops was not affected by farm location, farm distribution of cropland slope, or N application as all farms selected the same mix of crop rotations 1 and 5. Rotation 5 was adopted because peanut quota was limited. Expected net income was reduced by N overapplications because increased yields from higher applications did not compensate for higher N costs. Strategies to reduce N overapplication will be cost effective because they reduce N deliveries while increasing net income. Net income declined on the steep-sloped farm due to lower crop yields obtained on steeper land. Distance from water did not affect net income.

Reducing N Delivery

When N deliveries were reduced by 7500 pounds, expected net incomes declined 3 to 32 percent (Table 4) relative to the economic optimum. Net incomes declined the most (25 to 32 percent) on farms where N was applied at recommended rates. Net incomes on these farms fell below net incomes for farms applying N 20 percent above recommendations. Because farms applying N at recommended levels had the lowest per-acre N deliveries in the baseline, they achieved relatively less N reduction from using conservation practices compared to N overappliers (see Table 2). As a result, they had to use conservation practices (cover crops, idle land, and strip-till cotton) on more acres compared to N overappliers.

Table 4 results labeled "N applied 20% above recommended rates" reflect the assumption that the farm continued to overapply N by 20 percent relative to extension recommendations. N delivery reductions were achieved by shifting rotations or idling land. The results labeled "N applications shift from 20% above recommended to recommended rates" reflect the assumption that N overappliers could adopt recommended N application rates. N overappliers could achieve much of the required 7500 pound reduction in N delivery simply by shifting to recommended application rates. When the overapplier changed to the recommended N application rate, no land was idled and expected net income declined by only 3 percent relative to the baseline.

Where N was applied at recommended rates, net returns were reduced by 30 to 32 percent on farms farther from surface water compared to 25 percent on farms close to water. The farms farther from water had lower per-acre N deliveries in the baseline and achieved smaller reductions in N deliveries from conservation practices compared to

Table 2. N Delivery by Crop Rotation, Cropland Slope and Distance from Nearest Stream

	Sediment-Attached N Loss			Soluble N Loss			Total N Delivery to Stream, Average Distance to Stream: Close			Far		
	Cropland Slope											
Rotation number and name	5%	3%	1%	5%	3%	1%	5%	3%	1%	5%	3%	1%
	pounds/acre											
N applied at recommended rates												
1. CTC-CTP	26.2	15.7	8.3	24.4	24.9	26.1	38.4	33.3	30.5	28.4	27.3	27.4
2. CTP-NTC	23.1	13.9	6.9	20.4	19.5	20.0	32.8	26.9	23.7	23.9	21.6	21.0
3. CTP-MTW-NTSB-CTC	26.2	15.3	7.9	38.4	38.4	40.0	52.4	46.6	44.2	42.4	40.7	41.2
4. MTW-NTSB-NTC-CTP	25.1	14.9	7.4	32.4	30.6	30.8	45.8	38.6	34.8	36.2	32.8	31.9
5. MTW-NTSB-CTC	21.7	12.2	5.8	43.4	42.9	43.6	55.0	49.4	46.7	46.7	44.7	44.5
6. MTW-NTSB-STCC	20.7	11.7	4.8	40.6	40.6	41.1	51.6	46.9	43.7	43.8	42.4	41.8
7. CTCC-CTPC	26.5	15.5	8.1	20.4	20.0	19.6	34.6	28.3	23.9	24.4	22.3	20.8
8. STCC-CTPC	24.2	14.1	6.9	20.2	19.8	19.5	33.1	27.3	23.2	23.9	21.9	20.5
9. NTCC-CTPC	25.0	14.6	7.1	15.2	14.1	13.1	28.6	21.9	16.9	19.0	16.3	14.2
10. CTPC-MTW-NTSB-STCC	27.8	16.4	7.9	36.8	36.6	37.4	51.4	45.4	41.7	40.9	39.0	38.6
11. IL	2.4	1.3	0.6	14.8	14.6	14.8	16.1	15.3	15.1	15.2	14.8	14.9
N applied 20% above recommended rates												
1. CTC-CTP	26.3	15.8	8.3	27.7	28.3	29.8	41.8	36.8	34.2	31.7	30.7	31.1
2. CTP-NTC	23.4	14.1	7.0	23.3	22.8	23.4	35.8	30.3	27.1	26.8	24.9	24.5
3. CTP-MTW-NTSB-CTC	26.3	15.3	7.9	44.9	43.7	46.2	59.0	51.9	50.4	48.9	46.0	47.4
4. MTW-NTSB-NTC-CTP	25.5	15.1	7.5	39.0	37.6	37.6	52.6	45.7	41.6	42.9	39.9	38.7
5. MTW-NTSB-CTC	21.7	12.2	5.8	51.9	52.1	52.4	63.5	58.6	55.5	55.2	53.9	53.3
6. MTW-NTSB-STCC	20.5	11.6	4.9	53.1	53.9	54.3	64.0	60.2	57.0	56.2	55.7	55.0
7. CTCC-CTPC	26.5	15.4	8.1	20.9	20.6	20.1	35.1	28.8	24.4	24.9	22.9	21.3
8. STCC-CTPC	24.0	14.0	6.9	23.2	22.8	22.5	36.0	30.3	26.2	26.8	24.9	23.5
9. NTCC-CTPC	25.3	14.8	7.2	18.4	17.0	15.9	31.9	24.9	19.8	22.2	19.2	17.0
10. CTPC-MTW-NTSB-STCC	27.1	15.4	7.9	43.2	42.9	43.8	57.6	51.7	48.1	47.3	45.4	45.0

Table 3. Baseline N Delivery, Expected Net Farm Income, and Crop Acres for the Risk-Neutral Farm

Farm Slope/ Distance	N Delivery	Expected Net Income	Rotation Number and Name	Rotation Acres by Cropland Slope: 1% Slope	3% Slope	5% Slope	Crop Acres: Peanut	Cotton	Wheat/ Soybean
	lbs.	$							
N applied at recommended rates									
Flat-close	31,981	157,226	1. CTC-CTP	212		75	144	375	231
			5. MTW-NTSB-CTC	88	375				
Steep-close	32,932	155,788	1. CTC-CTP	64		225	144	375	231
			5. MTW-NTSB-CTC	161	300				
Flat-far	28,618	157,226	1. CTC-CTP	212		75	144	375	231
			5. MTW-NTSB-CTC	88	375				
Steep-far	28,719	155,788	1. CTC-CTP	64		225	144	375	231
			5. MTW-NTSB-CTC	161	300				
N applied 20% above recommended rates									
Flat-close	37,245	155,462	1. CTC-CTP	212		75	144	375	231
			5. MTW-NTSB-CTC	88	375				
Steep-close	38,111	154,038	1. CTC-CTP	64		225	144	375	231
			5. MTW-NTSB-CTC	161	300				
Flat-far	33,874	155,462	1. CTC-CTP	212		75	144	375	231
			5. MTW-NTSB-CTC	88	375				
Steep-far	33,876	154,038	1. CTC-CTP	64		225	144	375	231
			5. MTW-NTSB-CTC	161	300				

farms closer to water. These farms had to adopt conservation practices on more acres to achieve the 7500-pound N reduction, which led to greater reductions in net returns. The farm with steeper cropland incurred slightly larger reductions in expected net income than the farm with flatter cropland because it had less flexibility to shift the more profitable but erosive rotations from steep land to flat land. Consequently, the farm with steeper land had to idle more land to reduce N delivery.

Results with Risk Aversion

In the baseline on the farm with flatter cropland and farther from the stream, the preferred crop plans for the strong and moderate risk averters resulted in 7 to 12 percent more N delivery compared to the risk neutral case (Table 5).[5] The N delivery constraint reduced expected net income by 5 to 8 percent for the moderate and strong risk averters, less than the cost incurred by the risk-neutral farmer. Risk averters' costs were lower because their rotations produced higher per-acre N delivery in the baseline; consequently they achieved greater reductions in N delivery by shifting out of these rotations and had to use fewer conservation practices including cover crops and idling land to meet the delivery constraint. However, risk averters' costs increased with risk aversion, because reducing N delivery resulted in a riskier farm plan which was of greater concern to the strong risk averter. It is difficult to generalize about the effects of risk aversion on N reduction costs. The effects of risk aversion on N reduction costs are likely to depend on the site-specific characteristics of conventional and conservation crop practices (Bosch and Pease).

Sensitivity Analysis

The cost per pound of N reduction increased with total reductions in N delivery (Table 6).

[5] Ten plans were efficient for the moderate risk-aversion interval. Results shown in Table 5 are preferred for the lower bound (0.00001) of the moderate risk-aversion interval.

Table 4. N Delivery, Expected Net Farm Income, and Crop Acres for the Risk-Neutral Farm After 7500 Pound Reduction in N Delivery

Farm Slope/ Distance	N Deliv. Lbs.	Exp. Net Inc. $	Net Inc. Reduction $ (%)	Rotation Number and Name	Rotation Acres by Slope: 1% Slope	3% Slope	5% Slope	Crop Acres: Peanut	Cotton	Wheat/ Sb.	Cover	Idle
N applied at recommended rates												
Flat-close	24,481	125,954	31,272	6. MTW-NTSB-STCC		321		167	328	161	496	94
			(25)	8. STCC-CTPC	300	35						
				11. IL		19	75					
Steep-close	25,432	124,376	31,412	6. MTW-NTSB-STCC		198	128	164	326	163	489	97
			(25)	8. STCC-CTPC	225	102						
				11. IL			97					
Flat-far	21,118	121,218	36,008	6. MTW-NTSB-STCC		269		209	344	134	553	63
			(30)	8. STCC-CTPC	300	106	12					
				11. IL			63					
Steep-far	21,219	118,096	37,692	6. MTW-NTSB-STCC		257		212	340	128	551	70
			(32)	8. STCC-CTPC	225	43	155					
				11. IL			70					
N applied 20% above recommended rates												
Flat-close	29,745	129,808	25,654	5. MTW-NTSB-CTC		333		167	334	167	335	82
			(20)	8. STCC-CTPC	300	35						
				11. IL		7	75					
Steep-close	30,611	127,581	26,457	5. MTW-NTSB-CTC		300	31	164	330	165	328	91
			(21)	8. STCC-CTPC	225		103					
				11. IL			91					
Flat-far	26,374	125,907	29,555	5. MTW-NTSB-CTC		303		186	338	151	372	75
			(23)	8. STCC-CTPC	300	72						
				11. IL			75					
Steep-far	26,376	122,925	31,113	5. MTW-NTSB-CTC		299		175	325	149	349	101
			(25)	8. STCC-CTPC	225	1	124					
				11. IL			101					

Table 4. (Continued)

Farm Slope/ Distance	N Deliv. Lbs.	Exp. Net Inc. $	Net Inc. Reduction $ (%)	Rotation Number and Name	Rotation Acres by Slope			Crop Acres				
					1% Slope	3% Slope	5% Slope	Peanut	Cotton	Wheat/ Sb.	Cover	Idle
N applications shift from 20% above recommended to recommended rates												
Flat-close	29,745	151,491	3,971	1. CTC-CTP		126	75	152	375	223	326	
			(3)	6. MTW-NTSB-STCC	197	249						
				8. STCC-CTPC	103							
Steep-close	30,611	150,191	3,847	1. CTC-CTP			183	152	375	223	344	
			(3)	6. MTW-NTSB-STCC	104	300	42					
				8. STCC-CTPC	121							
Flat-far	26,374	151,635	5,591	1. CTC-CTP		111	75	152	375	223	341	
			(3)	6. MTW-NTSB-STCC	182	264						
				8. STCC-CTPC	118							
Steep-far	26,376	149,320	6,468	1. CTC-CTP			157	153	375	222	371	
			(3)	6. MTW-NTSB-STCC	76	300	68					
				8. STCC-CTPC	149							

Table 5. N Delivery, Expected Net Farm Income, and Crop Acres for Risk Averters Under the Baseline and After 7500 Pound Reduction in N Delivery[a]

Risk Aversion	N Deliv. Lbs.	Exp. Net Income $	Net Income Redn. ($) %	Risk Adj. Cost[b] ($)	Rotation Acres by Cropland Slope: Rotation Number and Name	1% Acres	3% Acres	5% Acres	Crop Acres: Peanut	Cotton	Wheat/ Sb.	Corn	Cover	Idle
Baseline														
Moderate[c]	32,155	156,479			3. CTP-MTW-NTSB-CTC	300	37	75	137	306	306			
					5. MTW-NTSB-CTC		338							
Strong[d]	30,761	141,125			4. MTW-NTSB-NTC-CTP	164		75	80	255	335	80		
					5. MTW-NTSB-CTC	136	375							
N delivery reduced by 7,500 pounds														
Moderate	24,655	143,538	12,941 (8)	15,692	1. CTC-CTP			15	158	367	210		510	15
					6. MTW-NTSB-STCC		375	44						
					8. STCC-CTPC	300								
					11. IL			16						
Strong	23,261	133,716	7,409 (5)	26,653	1. CTC-CTP		20	7	164	341	177		415	68
					5. MTW-NTSB-CTC		125							
					6. MTW-NTSB-STCC		230							
					8. STCC-CTPC	300								
					11. IL			68						

[a] Results are for the farm with flatter cropland located far from the stream, which applied N at the recommended rate.
[b] Amount the baseline net income distribution can be lowered before it no longer dominates net income obtained after the 7,500-pound N reduction.
[c] Absolute risk aversion coefficient = 0.00001.
[d] Absolute risk aversion interval = 0.00005 to 0.0001.

Table 6. Cost per Pound of N Reduction for Three Levels of Reduction in N Delivery for the Risk-Neutral Farm

Farm Slope/ Distance	3750 lb Reduction	7500 lb Reduction	15,000 lb Reduction
N applied at recommended rates			
Flat-close	3.04	4.17	5.36
Steep-close	3.25	4.19	5.06
Flat-far	3.38	4.80	5.53
Steep-far	3.81	5.03	6.11
N applied 20% above recommended rates			
Flat-close	3.02	3.42	4.11
Steep-close	3.39	3.53	3.92
Flat-far	3.28	3.94	4.52
Steep-far	3.83	4.15	4.56
N applications shift from 20% above recommended to recommended rates			
Flat-close	−0.50	0.53	2.93
Steep-close	−0.50	0.51	2.83
Flat-far	−0.50	0.51	3.32
Steep-far	−0.50	0.63	3.44

Varying the reduction in N delivery had little effect on the relationship between site factors and N delivery control costs. Farms located closer to water had lower costs per pound of reduction than farms farther from water. Farms which overapplied N by 20 percent had lower control costs than farms which applied at recommended rates. Overappliers who reduced their N application rates had the lowest costs at all levels of N reduction.

Conclusions and Implications

Cropland slope and distance to water, as well as farmers' risk aversion and information used to make fertilizer application decisions affected N deliveries to streams and costs of reducing N deliveries. Interrelationships between these factors affected the amount of N delivery and costs of reducing N delivery. Steeper slopes increased N deliveries more on fields located near surface water. Overapplying N relative to extension recommendations had the greatest impact on N deliveries for rotations which used large amounts of N. Farms which overapplied N had lower costs of reducing N deliveries because they could reduce N delivery by lowering application rates without reducing net returns. Farms located closer to surface water had lower costs of reducing N delivery because conservation practices were more effective in reducing N delivery compared to farms located farther from water. Changing the farmer's risk attitude from risk neutrality to risk aversion lowered the costs of reducing N delivery. Risk averters planted crop rotations with higher N delivery potential and achieved more N delivery reduction for reducing these rotations compared to risk neutrals.

The effects of N application rates on potential N delivery and costs of reducing N delivery indicate the cost effectiveness of programs such as subsidized nutrient management planning which help farmers reduce N applications to recommended levels. Such programs may involve short-term public costs, but considerable long-term social benefits in terms of lower N pollution potential and higher net farm income. Public subsidies of programs to reduce the risk of adopting conservation practices may achieve environmental benefits at relatively low cost (Agricultural Conservation Innovation Center). The finding of more cost-effective reductions on cropland located closer to water bodies illustrates that targeting farms for pollution reduction based on physical characteristics can reduce N pollution control costs. Policy makers need to identify the water quality goals for the watershed and determine which farms have the greatest potential effect on achievement of these goals. Targeted programs can be designed to influence farmer behavior on these farms in order to achieve the goal (National Research Council; Van Vuuren, Giraldez, and Stonehouse). Further studies should consider the effects on N pollution control costs of other farm physical characteristics such as soil leaching and erosion potential and socioeconomic characteristics such as farm enterprise type, size, financial leverage and farmers' information regarding crop nutrient requirements and sources.

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