Reducing Crop Nutrient Applications: The Yield Reserve Program

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Abstract

A proposed Yield Reserve Program designed to compensate farmers for any reduced yields resulting from reduced nitrogen (N) application rates below recommended rates is evaluated. Assuming that farmers currently follow extension recommendations for applying N, Yield Reserve Program participation reduces expected net revenue by $10 to $13/ha. The Yield Reserve Program reduces expected net revenue by $17 to $20/ha for farmers who apply N to maximize expected net revenue. Farmers' costs of participation increase with lower probabilities of inadequate rainfall and higher corn prices and decline with higher N prices. The Yield Reserve Program can significantly reduce N applications to cropland, which may reduce N content of surface waters, but the costs to taxpayers and farmers will depend on how the program is implemented.

Keywords: compliance cost, nitrogen fertilizer, nonpoint source pollution, policy, yield response function

Introduction

Agriculture is a major source of nonpoint source (NPS) pollution in the U.S., "degrading 60 percent of the impaired river miles and half of the impaired lake acreage" (USEPA, 2004). Agriculture has also been identified as the largest source of nitrogen (N) pollution affecting the Chesapeake Bay (Chesapeake Bay Foundation). Nitrogen and phosphorus (P) nutrients that leave fields as runoff promote eutrophication and algal blooms, which create anoxic conditions damaging to aquatic species (USEPA, 2006).

In the Chesapeake Bay agreement of 1987, cooperating states and the District of Columbia agreed to reduce nutrient loadings to the Bay by 40% from the 1985 baseline (Chesapeake Bay Agreement). As estimated by the Chesapeake Bay watershed model, the nutrient loadings goals were nearly achieved by 2000, but current water quality monitoring indicates continued peril for the Bay's living resources such as fish and aquatic vegetation (Chesapeake Bay Program, 2002). Recent model simulations indicate that only 58% of the P, 41% of the N and 54% of the sediment reduction goals necessary to assure sustainability of the Bay's living resources have been achieved (Chesapeake Bay Program, 2005). The 2010 goals of the Program include removal of the Bay and its tidal waters from the CWA 303(d) impaired waters list through achievement of established Tributary Strategies (Chesapeake Bay Program, undated).

State and Federal programs seek to mitigate NPS pollution originating from farms. One type of program involves 'green payments,' that is, paying farmers for adoption of Best Management Practices (BMPs) that mitigate pollution (Ribaudo, Horan, and Smith). The Conservation Reserve Program bidding program uses market determined land rental rates to pay farmers a fixed rate to remove highly erodible and other environmentally sensitive lands from production (USDA FSA). The Conservation Security Program provides incentive payments for adoption of nutrient management planning and applications (USDA NRCS, 2006). Recently, programs have provided insurance to farmers who reduce their nutrient applications to levels specified in Best Management Practices guidelines (USDA RMA; BMP Challenge). These programs insure against yield losses resulting from inadequate nutrient applications.

Economic analyses of green payment options have focused on policy instruments and methods of targeting policy instruments (Ribaudo, Horan, and Smith). Wu et al. found an inelastic acreage response to payments for adoption of conservation crop rotations and tillage implying that such programs would not be cost effective in addressing the hypoxia problem in the Gulf of Mexico. Zhang, Horan, and Claassen found that performance-based subsidies to reduce N runoff are first-best in that subsidy rates are optimally differentiated to reflect each farm's delivery of N loads. However, targeted nutrient management subsidies, which focus directly on reducing N applications, produce almost equivalent net returns compared to performance subsidies. This result implies that altering N use directly is more efficient than altering land use as a method of achieving nutrient reduction goals. While the need to focus directly on N (or P) reductions in order to reduce nutrient pollution is becoming clear, there is less certainty as to how this reduction can be achieved most cost effectively with green payments, an issue of high importance to policymakers and water quality program leaders. Nutrient management programs which induce farmers to reduce nutrient applications to recommended rates can provide 'win-win' opportunities to increase net returns and reduce pollution (VanDyke et al.). However, N applications at or below recommended rates may still result in N loss, because the crop is not perfectly efficient in removing applied N (Scharf and Alley).

Recently an innovative proposal has been made to reduce nutrient applications and nutrient pollution potential by compensating farmers to reduce their N applications below standard recommendations (Henry A. Wallace Center). Such efforts are labeled "yield reserve" because a portion of yield production potential is retired just as land is retired under the Conservation Reserve Program. This proposal, which has yet to be approved, faces implementation challenges such as verification of farmers' N applications and yields. Nonetheless, interest in the program concept among policymakers remains high (U.S. Congress, Senate, 2002a, 2002b). While the program has not been defined for all states, an analysis of the program could help policymakers better assess costs to taxpayers and farmers as well as to assess its potential to reduce environmental damage from N applications. The purpose of this study is to examine effects of a Yield Reserve Program on costs to farmers and taxpayers and potential reductions in N applications. This study uses existing yield data extrapolated to the Virginia coastal plain to analyze costs under three scenarios for implementation of a Yield Reserve Program: insurance payments, incentive payments, and a combined set of insurance and enhanced incentive payments.

Costs of Reducing N Applications

Farmers' potential costs of reducing N applications under the Yield Reserve Program are based on the opportunity cost of foregone net revenues from the N that is not applied. Foregone net revenues are calculated from the loss of yield and the savings in N and yield-related costs relative to those which would have been obtained prior to Yield Reserve. Assume a farmer's corn yield (Y) is given by

$$(1) Y = f(N, W, S)$$

where *N*, *W*, and *S* represent N application, weather conditions, and site specific characteristics, respectively. Expected net revenue (NR_p) above variable costs under the prior N application strategy is

$$(2)\ E(NR_p) = \sum_{i=1}^{I} pr_i \circ P_c \circ Y_{pi} - P_n \circ N_p$$

where N_p is the amount of N applied under the prior N application strategy; Y_{pi} is the corn yield obtained under the prior application strategy; P_n is the price of N, P_c is the price of corn (net of harvest, drying, and transportation costs per unit of yield), and pr_i is the probability of the *ith* weather state, which can take on I possible values (I is set to 47 in the empirical model described below). Other production costs besides N application are assumed fixed and invariant regardless of whether or not the farmer participates in the program. Under the Yield Reserve Program, a farmer's net revenue is given by

$$(3)\ E(NR_{yr}) = \sum_{i=1}^{I} pr_i \circ P_c \circ Y_{yri} - P_n \circ N_{yr}$$

where Y_{yri} represents the yield obtained under weather state i and with the N application mandated by the Yield Reserve Program, N_{yr}. Assuming risk neutrality, the farmer's potential cost of reducing N applications to comply with the Yield Reserve Program is

$$(4)\ \begin{aligned} & E(NR_p) - E(NR_{yr}) = \\ & \sum_{i=1}^{I} pr_i \circ P_c \circ Y_{pi} - P_n \circ N_p - \sum_{i=1}^{I} pr_i \circ P_c \circ Y_{yri} - P_n \circ N_{yr} = \\ & \sum_{i=1}^{I} pr_i \circ P_c \circ (Y_{pi} - Y_{yri}) - P_n \circ (N_p - N_{yr}) \end{aligned}$$

Potential cost of reducing N applications depends on corn and N prices, weather event probabilities, the prior N application strategy, and the amount of N applied under the Yield Reserve Program.

Prior N Applications

Farmers' N applications are affected by their perceptions of yield risk. Several studies have concluded that N is a yield risk-increasing input, with N applications for strong risk averters falling by 2% (Babcock, Chalfant, and Collender) to 30% (Rosegrant and Roumasset) to 80% (Lambert) below expected profit-maximizing levels. However, these conclusions were based on production functions estimated with experimental yields. SriRamaratnam et al. compared farmers' perceptions of yield risks and N applications with experimental data. While experimental results showed N to be risk increasing, farmers viewed N as risk reducing. Farmers' subjective yield expectations were more optimistic than comparable experimental results.

Babcock examined the effects of uncertain weather and soil N levels on N applications using a linear plateau response function. Increasing uncertainty about weather (rainfall) and soil N levels led to increased optimal N applications due to the asymmetry of losses from non-optimal N applications. Babcock demonstrated that with the plateau yield fixed at its mean level, if the price of N is less than half of its marginal product with N limiting, optimal N rates under weather uncertainty will be greater than under certainty. Similarly, uncertainty about soil N levels increases optimal N application rates when the marginal product of N is more than twice its price. While Babcock's results assume risk neutrality, he noted that risk aversion is likely to have little impact on N applications because, even if N is a risk-reducing input, varying N has relatively little impact on yield risk (Babcock; Babcock, Chalfant, and Collender).

Babcock's work implies that in many situations net revenue losses from sub-optimal N applications that are lower or higher than the optimum level are likely to be asymmetrical, meaning net revenue losses from applying too little N are greater than net revenue losses from applying too much. Yield risks from weather uncertainty and possibly asymmetric losses need to be considered in estimating farmers' potential costs of the Yield Reserve Program. Ignoring such loss asymmetry may lead to unrealistic projections of potential Yield Reserve Program costs and adoption rates by farmers.

Farmers' applications of N also may be heavily influenced by recommended rates of the Cooperative Extension Service, state agencies, crop consultants, and other advisors. Recommended rates are particularly important under a Yield Reserve Program as they are the baseline from which a 15-percent reduction in N application is calculated (Simpson).

Empirical Model

We developed an empirical model to estimate corn yields and net revenues under a prior N application strategy and with N applications constrained by the Yield Reserve Program. Expected net revenue is set equal to the yield times the price of corn, $102/Mg ($2.58/bu), net of transportation, drying and marketing costs of $7.14/Mg, ($0.18/bu), minus the N application times the price of N, $0.62/kg ($0.28/lb). Other costs are assumed fixed. Corn and N prices are the five-year average prices for 2000 to 2004 adjusted to 2005 dollars (USDA NASS, 2006). Nitrogen response functions under different rainfall patterns are estimated for N experimental trials in Virginia and North Carolina. Probabilities are assigned to seasonal rainfall based on historical weather data. Two prior N application strategies are considered: 1) N applications to maximize expected net revenues; and 2) N applications based on recommended rates of the Virginia Cooperative Extension Service. The Yield Reserve Program N application is set at 15 percent below the amount recommended by Virginia Cooperative Extension. Cooperative Extension fertilizer recommendations are often used as the target application level in nutrient management programs (Virginia Department of Conservation and Recreation). Even at these recommended rates, N losses to the environment can occur because of crop inefficiencies in removing applied N (Scharf and Alley).

Yield Response Curves

Experimental data from 2000-2003 (representing 15 site years) in North Carolina (Sripada et al.) and from 2002-2004 (5 site years) in Virginia (Phillips) were used to estimate corn yield response to N. The data were analyzed with quadratic linear regression and nonlinear regression utilizing the Mitscherlich function (Yaron et al.). The quadratic and the Mitscherlich equations produced similar results including R^2 values. The quadratic equation was selected because it is simpler to apply and interpret compared to a non-linear regression approach, and because the quadratic equations always produced non-zero values for all of the parameters, which was not the case for all of the Mitscherlich equations. The quadratic function takes the following form:

$$(5)\, Yc_j = \alpha + \beta N - \gamma N^2$$

where Yc_j equals observed yield, N is applied N, N^2 is the square of N, and α, β, and γ are estimated parameters.

All of the regressions produced significant models except for one site in 2002 in North Carolina and one site in 2002 in Virginia where low rainfall limited the impact of N fertilizer on yield. Three categories of yield responses were determined for the data. The data from 2003 and 2004 were used to form the high-yield group, because these years gave the highest response to N. Average yield groups were formed based on the 2000 and 2001 data, and the low-yield group was based on the 2002 data.

Weather Probabilities

Historical weather data were used to determine the probabilities of weather corresponding to high, average, or low yield conditions. Historic yields in Eastern Virginia for 47 years (1953-2004) were regressed against rainfall amounts during the growing season and trend. This regression facilitated grouping historical yields into three categories based on rainfall. The probabilities associated with the rainfall categories were used to weight yield response curves. The weighted yield response curves were used to determine optimal N applications and costs of restricting N applications based on weather probabilities.

Corn yield data were obtained from the National Agricultural Statistics Service from 1958 to 2004 for 28 counties in the Virginia Coastal Plain (USDA NASS). The study area forms the southeast portion of the Chesapeake Bay drainage area. Weighted average corn yield data were determined by summing the total production of corn for each year and dividing by the area harvested. Rainfall data were obtained from the Southeast Regional Climate Center's website (Southeast Regional Climate Center) for the corresponding years. In order to mitigate spatial variability in rainfall, rainfall data from five weather stations in the area were averaged.

Yields were regressed against a time trend (1958 = 1, 2004 = 47) and growing season rainfall. The regressors were each individually plotted against the response variable. The plots suggested that the regressors would have a better fit if square root of time trend and natural logarithms of monthly rainfall were used. After the transformations were completed, a regression was run using R-square and the encyclopedic (using all combinations of the variables) selection criteria in SAS (SAS). The best model, which is defined as the model which is most parsimonious, has highest R^2, and has all regressors significant, is shown below. The variables include square root of year trend (sqrtyear) and natural logarithm of rainfall in centimeters for each month (lnmay, lnjune, and lnjuly). The adjusted R-squared value is 0.75.

$$\text{(6) Yield} = -54.272 + 10.72239\text{sqrtyear} + 14.760\text{lnmay} + 20.504\text{lnjune} + 29.321\text{lnjuly}$$

$$(<.0001) \quad (<.0001) \qquad\qquad (.002) \qquad (<.0001) \qquad (<.0001)$$

where yield refers to Mg of corn per hectare and coefficient significance levels are shown in parentheses.

Equation 6 was used to derive detrended yields corresponding to rainfall conditions for each weather year. Based on the application of equation 6 to the historic rainfall and yield data, the lowest yield for 2003 and 2004 (years with good growing season rainfall) is 8.3 Mg/ha. The highest yield for 2000 and 2001 (years with average growing season rainfall) is 7.9 Mg/ha. The average of these yields, 8.1 Mg/ha, is used as the boundary between good and average yields. Similarly, the lowest estimated yield for 2000 and 2001 is 7.6 Mg/ha. The estimated yield for 2002, the year with low experimental yields is 5.6 Mg/ha. The average of the 5.6 and 7.6 yields, 6.6 Mg/ha, is used as the boundary between yields in average and poor rainfall years. There were 6 years that fell into the highest yield group, 23 in the average yield group, and 18 in the low yield group. The corresponding probabilities of these types of years occurring are 13 percent for a good (high-yield) year, 49 percent for an average (average-yield) year, and 38 percent for a bad (low-yield) year.

Soil Productivity Groups

The soil on which each experiment was conducted is classified in a Soil Productivity Group as defined in the Virginia Nutrient Management and Standards Criteria (Criteria) (Virginia Department of Conservation and Recreation). The potential yields assigned to each Soil Productivity Group in the Criteria were used to apply yield response curves from the experiments to other soils. An adjustment percentage was calculated, which equaled the ratio of potential yield for each Soil Productivity Group relative to the Productivity Group on which the experiment was conducted. Adjustment percentages were multiplied by the linear and quadratic terms in each yield response curve to obtain estimated yield responses to N for the soil groups not included in the field experiments. The intercepts were not adjusted because yields on different soils in the study area are not expected to vary greatly at low levels of fertilizer application.

Total areas in Soil Productivity Groups I, II, and III in the Virginia Coastal Plain were quantified using soil profiles obtained from the USDA Natural Resource Conservation Service's Soil Data Mart (USDA NRCS, no date). The corn acreage in each Soil Productivity Group was estimated by multiplying its percentage share of the total area in groups I, II, and III times the average amount of corn acreage for the Virginia Coastal Plain for 2000-2004 (USDA NASS). Although the Criteria define 5 soil productivity groups, only Soil Productivity Groups I, II, and III are included because they account for almost all corn production in the study area.

N Applications

Two prior N application strategies, the first based on Cooperative Extension recommendations and the second based on expected net revenue maximization, were considered. Cooperative Extension recommendations are 196, 174, and 152 kg N/ha, respectively, for Groups I, II, and III. Cooperative Extension N fertilizer recommendations are based on an efficiency of 0.02 kg N/kg grain (1.0 lb N/bu) of corn grain production potential for individual soil series (Virginia Department of Conservation and Recreation). Yield potential for each soil series is established from yield records over several years (usually 5) from research and on-farm trials. Virginia corn yield potential levels for individual soils were updated in 2005 (Baker). The N fertilizer recommendations will generally be the rate that will achieve 90 to 95% of maximum yield potential based on corn yield response to N fertilization trials.

The N application that maximizes net revenue on each of k =3 soil productivity groups is estimated as follows:

$$(7)\, Max\; NR_{ik} = \sum_{j=1}^{20} Y_{ijk}(N_{ik})P_c\, pr_{jk} - N_{ik}P_n \;:\; i = 1...41$$

where pr_{jk} is probability of obtaining a yield response of Y_{ijk} for an application rate of N_{ik} on the k^{th} Soil Productivity Group. For the i^{th} N application on Soil Productivity Group k there are j = 20 possible yield responses (depending on weather and site conditions) corresponding to the 20 yield response equations estimated for the experimental sites as applied to the k^{th} Soil Productivity Group. For a given Soil Productivity Group, the composite, weighted- average yield response function is obtained by summing the yield response of each equation for an experimental site (as applied to that Soil Productivity Group) multiplied by its probability. The probability of each yield response equation is related to growing season rainfall (good rainfall probability = 0.13, average rainfall probability = 0.49, and poor rainfall probability = 0.38) as follows. Each yield response estimated for a given type of rainfall year is assumed to be equally likely. Each of the 10 equations estimated for good rainfall years (2003 and 2004) is given a probability of 0.13/10 = .013. Each of the 7 equations estimated for average rainfall years (2000 and 2001) has a 0.49/7 = 0.07 probability and each of the 3 equations estimated for low rainfall years (2002) has a 0.38/3 = 0.127 probability.

The expected net revenue maximizing strategy is found by searching over 41 potential application rates varying in 9 kg/ha (8 lb/ac) increments from 0 to 360 kg/ha (320 lb/ac). Expected net revenue maximization occurs at N applications of 225, 216, and 207 kg/ha for Soil Productivity Groups I, II, and III, respectively.

Farmer Compensation and Taxpayer Costs

Farmers' expected costs of the Yield Reserve Program are equal to estimated expected net revenue in the baseline using the prior N application strategy minus expected net revenue under the Yield Reserve Program prior to compensation. Expected costs may be offset by compensation. Three compensation scenarios are investigated: insurance-only, incentive-only, and a combined set of insurance and enhanced incentive payments. The insurance-only scheme provides compensation to the participating farmer during a year when yield losses occur due to applying N below recommended rates. Losses are compensated at the assumed market price. Losses are certified by planting check strips in the field, which are fertilized at recommended rates. The incentive-only scheme provides the farmer a fixed annual payment equal to the expected value of net revenue losses from applying N at a rate 15 percent below the extension recommended levels. There is no insurance adjustment for yield losses under this scheme. The incentive scheme takes account of savings realized by a farmer from reduced N applications and reduced harvest, transportation, and marketing costs for the lower yield.

The combined set of enhanced incentive and insurance payments is expected to provide the highest overall level of compensation to farmers and, therefore, to induce the widest level of participation. This option provides an enhanced incentive payment of $74 per hectare ($30 per acre), which is higher than the expected level of the incentive payment under option 1. In addition, the program provides an insurance payment, which covers yield losses in years when yields are reduced due to lower fertilizer rates (Sweeney). For all three compensation schemes, yield losses are calculated relative to the yields that would have been earned from applying N at the level recommended by extension. If net revenue-maximizing N applications are higher than extension recommendations, farmers' losses may be higher.

Cost of the program to taxpayers under each payment scenario (assuming 100 percent farmer participation) is estimated by summing farmer incentive and insurance payments plus administrative costs times the estimated number of hectares of corn produced in the Virginia Coastal Plain. Administrative costs for verifying N applications and yield losses under the Yield Reserve Program are estimated as $7.40/ha (Simpson).

Results

Assuming farmers currently follow extension recommendations in applying N, the estimated cost to farmers of the Yield Reserve Program (reduction in expected net revenue) ranges from $13 (Soil Group I) to $10 (Soil Group III) per ha (Table 1). Costs are incurred because of yield reductions averaging 0.3 Mg/ha. The costs are lowered somewhat by savings from reduced N applications, which fall by 29, 26, and 23 kg/ha on Soil Groups I, II, and III, respectively. Costs are higher on higher productivity soil groups because they have slightly greater yield losses from reduced N applications.

If current N applications are based on net revenue maximization, farmer costs per ha of the Yield Reserve Program are higher: $17 (Soil Group I) to $20 (Group III) (Table 1). Costs are higher because the Yield Reserve Program imposes larger restrictions on N applications by net revenue maximizers. When farmers apply N to maximize expected net revenue, N application rates are higher compared to extension recommendations. For example, N application on Soil Group I increases from 196 to 225 kg/ha, a 15 percent increase (Table 1, row 1). The 15-percent reduction in N application under the Yield Reserve Program is computed based on extension recommendations; consequently, the N application on Soil Group I is reduced by 58 kg/ha (compared to a 29-kg/ha reduction for those following extension recommendations). However, expected costs of the Yield Reserve Program are still not large—the largest cost of $20 for Soil Group III is less than 4 percent of baseline expected net revenue. N applications higher than extension recommendations bring only modest yield increases, 0.2, 0.3, and 0.4 Mg/ha on Soil Groups I, II, and III, respectively, and net revenue increases, $4, $8, and $10/ha, respectively (Table 1, rows 2 and 3). Consequently, the reductions in net revenues from the Yield Reserve Program are not much larger (in absolute terms) for net revenue maximizers than for those following extension recommendations.

Yield reserve compensation and mean net revenue with compensation (Table 2) are the same for both N application strategies because N applications are restricted to the same level, 15 percent below Cooperative Extension recommendations. The Yield Reserve Program compensation under the incentive-only scheme is set equal to the expected cost of the program with N applications restricted to 15 percent below extension recommendations (Table 2). Incentive-only compensation of $10 to $13/ha (Table 2) covers only one half to three fourths of the $17 to $20 costs of the Yield Reserve Program for net revenue maximizers (Table 1). Insurance-only compensation ($27 to $39/ha) is up to three times larger than incentive-only compensation. With insurance, all reductions in yield from the extension baseline are compensated at the market price. Savings from reduced N applications and reduced yield transportation costs are not deducted from compensation paid to farmers as is the case under the incentive-only scheme. Compensation under the enhanced-incentive plus insurance plan is highest of the three plans evaluated, three to four times higher than the insurance-only plan (Table 2). Compensation includes coverage of yield losses relative to yields under the extension baseline plus an enhanced incentive of $74/ha. The $74 enhanced incentive is larger than expected costs of the Yield Reserve Program.

After factoring in the Yield Reserve Program compensation, expected net revenue per ha is generally larger under the Yield Reserve Program compared to the baseline for all soil groups (Table 2 versus Table 1). The one exception is incentive-only compensation under the net revenue-maximizing baseline for which expected net revenues decline by $4 to $10/ha. Farmers seeking to maximize expected net revenues should have incentives to participate if their prior probabilities of yield reductions under the Yield Reserve Program match those used in this study.

Sensitivity Analysis

Farmers may tend to forget the bad years and overestimate the response of yields to N (Sri Ramaratnam et. al.; Pease), which would increase the perceived costs of the Yield Reserve Program. The sensitivity of expected costs of the Program to perceived yield probabilities is examined under two additional weather probability scenarios. In the first scenario, farmers are assumed to forget all but the most extreme bad years. The year 2002 is the most recent drought year with poor yields and has the 7th lowest predicted yield in the past 47 years based on the trend model (equation 6). Predicted yields for 2002 (equation 6) are used as the cutoff for low yield years. Only years with yields lower than those predicted for 2002 are included as low yield years with other years being reclassified as average years. The resulting probabilities are 72, 15, and 13 percent for average, bad, and good years, respectively. In the second scenario, farmers are assumed to forget all bad years, which are reclassified as average years. Resulting probabilities for average and good years are 87 percent and 13 percent, respectively. In this scenario, estimated equations for 2002 are not used in estimating yield losses under the Yield Reserve Program. In both scenarios, N applications are based on extension recommendations.

Under scenario 1, expected costs of the Yield Reserve Program are almost double compared to cost estimates based on initial probabilities, with costs ranging from $26 on Soil Group I to $19 on Soil Group III. Under scenario 2, expected costs of the Yield

Reserve Program are almost triple the initial costs estimates ranging from $35 on Soil Group I to $24 on Soil Group III. Costs of the Yield Reserve Program are low or even negative in drought years because there is little or no crop response to N and farmers save money by applying less N. Lowering the probability of drought years reduces this advantage of the Yield Reserve Program and increases the expected cost. However, under both scenarios, expected costs are only 3-4 percent of baseline expected net revenues.

Increases in the cost of N would lower costs of the Yield Reserve Program as farmers save more money from lowering their N applications. A 25 percent increase in the price of N (to $0.77/kg) lowers the expected cost of the Yield Reserve Program by $5, $4, and $3 on Soil Groups I, II, and III, respectively (30 to 38 percent reduction) with N applications based on extension recommendations. Increased corn prices raise the value of yield losses from lowering N applications and increase the costs of the Yield Reserve Program. A 25 percent increase in corn price raises expected cost of the Yield Reserve Program by more than 50 percent to $17 to $21/ha.

Taxpayer costs

Taxpayer costs of the Yield Reserve Program in the Virginia Coastal Plain vary significantly by compensation scheme. The lowest cost plan is incentive-only with a total cost of approximately $1.6 million (Table 3). Costs are low because savings from reduced N and crop transportation costs are accounted for and reduce the amount of payment. Based on the estimates presented here, farmers following extension recommendations would just break even with no additional compensation for bearing risk. The insurance plan would be twice as expensive as the incentive-only plan because farmers are compensated for yield losses while savings from reduced N and reduced crop harvest costs are not deducted from farmers' compensation. The cost of the proposed enhanced- incentive plus insurance plan, $9.7 million, is six times more expensive than the incentive-only plan, because it includes an insurance payment plus an enhanced incentive payment, $74/ha, which is higher than the estimated expected cost of the Yield Reserve Program to farmers.

McCann and Easter estimate an average transaction cost of $30.94/ha for all agricultural conservation programs, which is almost four times higher than the $7.40 rate used in this study. If the $30.94 rate were used, taxpayer costs would increase to $3.6, $5.4, and $11.8 million, respectively, for incentive, insurance, and enhanced-incentive plus insurance compensation schemes.

Yield Reserve Program costs per kg of N reduction depend on how N reductions are defined and the baseline from which reductions are measured. Here N reductions are defined as reductions in residual N, which is defined as the amount of applied N not removed by the crop. Crop removal is estimated as crop yield for the given N application amount (Table 1) times N removal per unit of yield. Corn removes an estimated 16.1 kg N per Mg of grain harvested (Virginia Cooperative Extension Service).

Bosch et al. conducted a survey of farmers' nutrient application practices in a portion of the study area. They concluded that most surveyed farmers applied close to extension recommended levels of N. If this finding holds generally true in the study area, total residual N reductions are an estimated 1.8 million kg and costs per kg of N reduction are $0.91, $1.88, and $5.47 per kg, respectively, for incentive-only, insurance-only, and enhanced-incentive plus insurance plans (Table 3). If farmers apply N to maximize expected net revenue, the estimated reduction is almost 3 times larger, 5.2 million kg. Compared to the extension baseline, estimated costs per kg of residual N reduction are one third as high—$0.31, $0.64, and $1.86 per kg, respectively, for incentive-only, insurance-only, and enhanced-incentive plus insurance plans.

Summary and Conclusions

Policymakers are searching for ways to reduce NPS pollution from farms. A Yield Reserve Program proposal would compensate farmers for reducing N applications by 15 percent below extension recommendations. This study analyzes the policy proposal for the Virginia Coastal Plain under three compensation plans: incentive-only, insurance-only, and enhanced-incentive plus insurance.

Assuming farmers follow extension recommendations in applying N, expected costs of the Yield Reserve Program (reductions in expected net revenue from limiting N applications) are $10 to $13/ha or 3 to 4 percent of baseline expected net revenue. Costs are somewhat higher for farms who apply N to maximize expected net revenue, $17 to $20/ha, but still less than 4 percent of expected net revenue. Reducing the probability of low rainfall years increases the expected cost of the Yield Reserve Program because yield penalties from limiting N applications are highest under average to good rainfall years. However, even with all low rainfall years removed, costs are $35/ha or less. Yield Reserve Program costs are sensitive to N and corn prices. Increasing the N price lowers Program costs because farmers save more money from the lower N applications.

Increased corn prices increase Program costs because of the higher value of yield losses from lower N applications.

Taxpayer costs would be lowest under the incentive-only plan, which limits compensation to expected costs of Yield Reserve Program participation. Insurance-only and enhanced-incentive plus insurance plans would have higher costs due to higher compensation paid to farmers and costs of administration. The taxpayer cost per kg reduction in residual N is sensitive to the incentive scheme and the assumed N application in the baseline prior to the Yield Reserve Program. If farmers follow extension recommendations, average costs per kg reduction in residual N vary from \$0.91 to \$5.47/kg depending on compensation.

The Yield Reserve Program can reduce N applications, and can potentially reduce nutrient pollution in waterways. The level of farmer participation and costs to taxpayers and farmers will depend on how the program is implemented. Whether the Yield Reserve Program is implemented and at what level will depend on perceived benefits of nutrient reduction, costs of alternative programs for reducing nutrient pollution, and other factors. Several issues related to the economic viability of yield reserve for nutrient pollution control require further study. The transactions costs of yield reserve and other approaches to reducing nutrient pollution should be compared (McCann and Easter). The potential to enhance the cost effectiveness of yield reserve by targeting payments should be investigated (Carpentier, Bosch, and Batie; Zhang, Horan, and Claassen). The effect of recent weather on farmers' perceived yield risk and perceived costs of the Yield Reserve Program deserves more study. Because land and machinery costs are variable in the long run, farmers' costs of participation could rise as these costs are spread over lower yields. These costs should be estimated to determine if they present significant barriers to participation. The potential effects of drawing down soil residual N levels on Yield Reserve Program participation and costs should be examined further (Brown; Yadav, Peterson, and Easter). Reductions in yields from reduced N applications may increase over time in such fields thus increasing farmers' participation costs and perhaps the compensation necessary to induce farmers to participate. Finally, the relationship between recommended rates and profit-maximizing rates should be regularly reassessed in light of constantly increasing corn yields and ethanol-induced higher corn prices. Stable recommended rates over as much as 10 years fail to account for yield and price impacts that will affect willingness of farmers to participate in a Yield Reserve Program.

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Table 1. Effects of Yield Reserve Program Scenarios on N Applications, Mean Yields, and Mean Farmer Net Revenues

		N Applications Based on					
		Cooperative Extension Recommendations			Maximizing Expected Net Revenue		
	Units	Soil Prod Group I	Soil Prod Group II	Soil Prod Group III	Soil Prod Group I	Soil Prod Group II	Soil Prod Group III
Baseline							
1. N application	kg/ha	196	174	152	225	216	207
2. Mean yield	Mg/ha	8.0	7.4	6.8	8.2	7.7	7.2
3. Mean net revenue	$/ha	639	593	550	643	601	560
Costs of reduced N applications under Yield Reserve Program							
4. N application	kg/ha	167	148	129	167	148	129
5. Mean yield	Mg/ha	7.7	7.1	6.5	7.7	7.1	6.5
6. Mean net revenue	$/ha	626	582	540	626	582	540
7. Mean cost (row 3 – row 6)	$/ha	13	12	10	17	19	20

Table 2. Compensation and Farmer Net Revenue under Yield Reserve Program[a]

	Soil Prod Group I	Soil Prod Group II	Soil Prod Group III
1. Mean net revenue before compensation	626	582	540
Yield Reserve Program compensation ($/ha)			
2. Incentive only	13	12	10
3. Insurance only[b]	39	33	27
4. Enhanced incentive + insurance[c]	113	107	101
Mean net revenue with Yield Reserve Program compensation ($/ha)			
5. Incentive only (row 1 + row 2)	639	594	550
6. Insurance only (row 1 + row 3)	665	615	567
7. Enhanced incentive + insurance (row 1 + row 4)	739	689	641

[a]Compensation and net revenues apply to both N application strategies.
[b]Amounts shown are mean payments. Payments vary from 0 to a maximum of $115 (Group I), $98 (Group II), and $81 (Group III).
[c]Amounts shown are the mean insurance payment (row 3) plus an enhanced incentive payment of $74/ha (Simpson, 2005). Payments per ha vary from a minimum of $74 to a maximum of $189 (Group I), $172 (Group II), and $155 (Group III).

Table 3. Reduced N Applications and Mean Taxpayer Costs of Yield Reserve

	Soil Group I	Soil Group II	Soil Group III	Total
Residual N reductions (kg)				
Extension recommendation baseline	321,823	702,360	751,539	1,775,722
Maximum revenue baseline	658,021	1,894,917	2,663,981	5,216,919
Taxpayer costs ($)				
Incentive only				
Total cost	$266,000	$623,162	$723,474	$1,612,636
Cost/ha	$20	$19	$18	$19
Cost/kg residual N reduction (extension baseline)	$0.83	$0.89	$0.96	$0.91
Cost/kg residual N reduction (maximum revenue baseline)	$0.40	$0.33	$0.27	$0.31
Insurance only				
Total cost	$611,800	$1,311,920	$1,406,755	$3,330,475
Cost/ha	$46	$40	$35	$39
Cost/kg residual N reduction (extension baseline)	$1.90	$1.87	$1.87	$1.88
Cost/kg residual N reduction (maximum revenue baseline)	$0.93	$0.69	$0.53	$0.64
Enhanced incentive + insurance				
Total cost	$1,596,000	$3,738,972	$4,381,037	$9,716,009
Cost/ha	$120	$114	$109	$113
Cost/kg residual N reduction (extension baseline)	$4.96	$5.32	$5.83	$5.47
Cost/kg residual N reduction (maximum revenue baseline)	$2.43	$1.97	$1.64	$1.86

[a]Costs are mean values for the Virginia Coastal Plain assuming 100 percent participation on corn acres. Costs include farmer compensation plus a $7.40/ha administrative cost.