STAFF PAPER

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An Economic Analysis of Soil Erosion Control and Low-Input Agriculture[*]

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ABSTRACT: *The Chesapeake Bay is a major water resource whose quality has been threatened by soil erosion and agrichemical contamination. The control of agricultural pollution of the Bay is one of the focal points of the 1987 Chesapeake Bay agreement formed by four states in the Bay's watershed (Virginia, Maryland, Pennsylvania, and the District of Columbia). Among the suggested solutions is the promotion of low-input agricultural practices. However, some low-input practices also include frequent cultivations of the soil for non-chemical weed control practices, which may induce erosion.*

This analysis uses a case study approach to determine agricultural practice selection and potential erosion under different soil erosion constraints. A multi-period mathematical programming model was used to determine the preferred agricultural practices for a farmer maximizing net returns in Richmond County, Virginia. Richmond County is adjacent to the Rappahanock River and above the Columbia aquifer, major sources of fresh water for the Chesapeake Bay. A range of agricultural practices was available, including conventional and organic practices. Soil erosion and the level of chemical and nitrogen losses through sedimentation and leaching are discussed in this article. Soil erosion constraints were introduced that reduced erosion by 10, 20, 30, 40, and 50 percent from current levels. These constraints were met without idled cropland, besides that enrolled in the Conservation Reserve Program or Virginia's mandatory Buffer Strip Program. The results of this study illustrate that soil conservation policies and low-input practices produce few environmental tradeoffs between erosion control and the reduction of agrichemical pollution.

Despite a long history of soil conservation programs, soil erosion remains a serious environmental problem in the United States. Early programs were designed to target the loss of agricultural productivity through soil erosion. New technologies, such as minimum tillage practices and chemical weed control, seemed to diminish the threat of soil erosion. However, water quality concerns of the late 1970's and early 1980's found soil erosion to still be a major contaminant of water bodies (26). The 1972 Federal Water Pollution Control Act Amendments specifically targeted water pollution by agricultural soil erosion and the agrichemicals carried by it (24).

The principal off-site damage of soil erosion is turbidity which reduces the available light for submerged aquatic plants, thereby threatening the food supply for aquatic animals (16). The second major consequence of soil erosion is the transport of nutrients and agrichemicals to surface water bodies (16). Phipps and Crosson (17) estimate that between 50 and 70 percent of nutrients reaching surface water are delivered by soil erosion. Although some agrichemicals are carried to water bodies in sediment, runoff is a more important mode of transport for these chemicals.

Both problems were addressed in the 1990 Food, Agriculture, Conservation, and Trade Act's revised Conservation Reserve Program (21). The 1985 Conservation Reserve Program (CRP) was designed to remove highly erodible land from production, while compensating landowners. The 1990 CRP program was expanded to include not only a soil erosion criterion but criteria based on the water quality benefits derived from putting land into CRP. With the 1990 farm bill has also come the strongest movement to adjust federal commodity programs, so that alternative or low-input farming practices can be utilized by producers without penalty.

The interest in the use of low-input practices or other alternative farming practices as a voluntary pollution control policy is the result of a rising public awareness of the ecological impacts of agriculture. Low-input practices utilize lower levels of chemicals and fertilizers and fewer deep tillage practices. The maintenance of soil fertility is achieved through crop rotations, residue cover, legume and non-legume cover crops, reduced tillage, and soil conservation structures.

Previous Work

Much literature exists on the physical impacts of soil erosion (9, 12, 22). The literature exploring the impacts from soil conservation is controversial. Both on-site and off-site erosion impacts occur, and the measurement of soil conservation program benefits or of soil erosion costs depends on the type of impacts included. Farm level impacts of erosion have been well documented (14, 18, 19), as well as the impact of conservation policies on farm income (1, 23). Prato and Wu (21), Frevert and Crowder (10), and Prato et al. (20) extended these economic benefits to the watershed level. Prato and Wu specifically addressed the soil conservation benefits from low-input farming practices. Many other studies have examined the economics of low-input practices (7, 11), but few have specifically addressed soil erosion (8). In this study, a range of production practices, organic, low-input and conventional, was available to the producer. The objective of this study was to determine a profit-maximizing set of agricultural practices under soil erosion constraints and to estimate soil erosion and associated chemical and nitrogen losses. The analysis was multi-year, and returns and environmental impacts were estimated at the county level.

The Study Area

Richmond County, Virginia is adjacent to the Rappahanock River and lies above the Columbia aquifer, which are major sources of fresh water for the Chesapeake Bay. The quality of the Chesapeake Bay recently has been of concern to recreationists, the fishing industry, and wildlife managers. Much of the Bay's vegetation and animal life is endangered by the high level of nitrogen, phosphorus, and agrichemical contaminants carried there by runoff, groundwater, and sediment (28). Total cropland in the county in 1988 was 32,317 acres, used for either planting, Conservation Reserve Program, buffer strips, or set-aside as required by the federal commodity programs (27). In 1987, the Chesapeake Bay Agreement was signed by Virginia and three other states in the Bay's watershed; Pennsylvania, Maryland, and the District of Columbia. Specific objectives of this agreement are to conserve soil resources and reduce erosion and chemical and nutrients reaching the Chesapeake Bay. One of the goals under this agreement is a 40 percent reduction of nitrogen and chemicals entering the Bay (3).

Agricultural sources of contaminants and sediment were identified as primary contributors to the Chesapeake Bay's degradation. Producers in the area and on major tributaries of the Bay have been targeted to reduce their agrichemical losses through runoff, leaching, and sediment. Programs are being developed to promote alternative tillage practices and the use of rotations, cover crops, green manures, and other types of low-input practices. Without adoption of these practices, producers may face stiff regulations and could be required to idle productive land in order to meet the goals of the Chesapeake Bay Agreement.

Study Methods

A 15-year mathematical programming model was developed, which incorporates a regime of production practices, simulated soil erosion coefficients, chemical levels in erosion, and nitrogen levels associated with erosion and leaching.

Production Activities. A personal non-random survey of 38 farmers in Richmond County was conducted to collect data on the characteristics of conventional farming practices and to assess what low-input practices were already in use. The survey results were summarized by A. B. Giuranna, B. Dietz, M. Ross, D.B. Taylor, and S.S. Batie at Virginia Polytechnic Institute and State University in an unpublished paper. This information was augmented by the expert advice of Virginia Cooperative Extension weed scientist, Scott Hagood, and Richmond County Agriculture Unit Director, Kelly Liddington, to construct four basic rotations and 34 total production activities. The production activities are summarized in Table 1. Different fertilization and chemical application rates; nitrogen sources (commercial nitrogen, poultry litter, and legumes); and non-chemical weed control practices were added to the four basic rotations to create a regime of practices ranging from conventional, activity 1, to completely organic, activities 5L, 11L, and 16L, production practices.

Crop yields, prices, and weather data were based on the 15-year period of 1970-1985. Prices were adjusted to remove the influence of inflation and put in 1988 dollars. Annual crop yields were the 15-year detrended county averages. Individual crop yields by production activity were unavailable; therefore, extension specialists recommended yield penalties for crops grown in activities with very low chemical levels, activities 3 and 3L, or completely organic activities, activities 5L, 11L, and 16L. Corn yields were penalized by 20 percent in all these activities; soybean yields were penalized by 20 percent in activities 3, 3L, and 5L and by 25 percent in rotations including a winter cover crop, 11L and 16L. The multi-year characteristic of the model facilitates accounting for nitrogen available from cover crops and legumes for subsequent crops, as well as nitrogen from residue decay.

Soil Erosion Coefficients. The simulation models, CREAMS, Chemicals, Runoff, and Erosion from Agricultural Management Systems (13), and GLEAMS, Groundwater Loading Effects of Agricultural Management Systems (15), were used to estimate soil erosion coefficients and nitrogen and chemical levels in this erosion (4). A modified Universal Soil Loss Equation estimates detachment that occurs when sediment is less than transport capacity. It also estimates transport occurring after surface saturation and deposition occurring when sediment load exceeds transport capacity. Annual cumulative soil loss were the coefficients used in this study. Six major soil types occur in Richmond County. A Virginia Geographical Information Systems map, obtained from Dr. V. Shanholtz, Director of Information Support Systems, at Virginia Polytechnic Institute and State University; and the Soil Survey of Richmond County (25) were used to select the prominent soil type under agricultural use, Suffolk sandy loam. This soil has moderate to medium permeability, slow to medium surface runoff, and a surface layer low in organic matter. Soil parameters included the fraction of clay (15%), silt (25%), and sand (60%) in the surface soil layer. The soil erodibility, or K factor, of 0.2 tons per acre was used.

This article addresses soil erosion, the levels of nitrogen and chemicals in the erosion, and nitrogen in leaching; however, nutrient and chemical losses through runoff and leaching were also accounted for in the economic model.

The General Model. The economic model maximized net returns to land, management, and capital for a 15-year period, starting in 1988. All agricultural land was included, therefore, returns were to all land not a single farmer. Net returns were discounted at 6 percent. The 15-year period has the same production and weather characteristics as 1970-1984.

All 34 production activities were available in every year. The model was not restricted to use a single production activity annually, i.e., combinations were permitted. No transition period to low-input practices was modeled, and production activities could be changed annually without cost. Agricultural commodity programs, federal set-aside requirements, and the CRP program were included in the model. Base acres and base yields were averaged and constrained according to the provisions of the 1985 farm bill by nonlinear equations.

The production practices in the Base Policy Scenario were representative of current farming practices. Two types of restrictions were necessary in this scenario in order for the model to represent current decision-making in Richmond County. The first restriction was the use of the yield penalties for low chemical and organic production activities, as previously discussed. In addition, a penalty was placed on the value of poultry litter. Poultry litter was assumed to be transported in from the Shenandoah Valley for use in Richmond County. A $.020 per pound penalty was placed on the initial estimated poultry litter price of $.066 (6). Little poultry litter was being used in the county during this study, but much research was being conducted on the possible uses and disposal techniques for poultry litter. The penalty was assessed because of the unknown costs in a potential poultry litter market and unknown costs for the application of poultry litter in the field. The Base Policy Scenario also had a 10 percent labor requirement penalty on activities 3, 3L, 5L, 11L, and 16L to account for possible additional labor needed on these low-chemical and organic production practices (6).

After the Base Policy Scenario was obtained, soil erosion constraints were added. Soil erosion was reduced by 10, 20, 30, 40, and 50 percent. Note that the goal of the Chesapeake Bay Agreement was a 40 percent reduction in soil erosion and chemicals introduced to the Bay. The GAMS, General Algebraic Modeling System (2), was used to solve the model.

Results

The selection of agricultural practices and 15-year total net returns under each of the soil erosion constraints are summarized in Table 2. Although any number of activities could be used each year, one or two activities dominated by acreage; these activities appear in Table 2. Table 3 contains the 15-year total erosion estimates and the associated levels of nitrogen and agrichemical loadings. Below these totals in parentheses is the change from the Base Policy Scenario. All chemical levels in potential percolation and runoff were reduced under the soil erosion constraints, except where new chemicals appeared as substitutes for the original chemicals. Nitrogen levels in runoff were also reduced; however, nitrogen levels in percolation rose in the more restrictive scenarios. The nitrogen levels in percolation are presented in Table 3 as the only significant environmental tradeoff under the soil erosion control scenarios.

10 Percent Reduction Scenario. The 10 percent reduction target was a 15-year total of 794,481 tons of soil erosion. Under this restriction, there were only 3 years in which the production activity was altered from the Base Policy Scenario. Activity 3 was partially substituted for activity 1 in year 3, and activity 15 was added to activity 1 in year 10. Years 3 and 10 had the highest soil erosion in the Base Policy Scenario, so under the 10 percent reduction constraint, these years were targeted for alternative practices. By using activity 3 in year 3, approximately 18,960 tons of soil were conserved. Activity 3, compared to activity 1, uses a chisel plow instead of a moldboard plow to prepare the seedbed for corn planting, with the same corn/small grain-double cropped soybean rotation as activity 2. Activity 15, used in year 10, reduces erosion by 69,156 tons by using a winter cover of rye mixed with crimson clover and disking the seedbed for corn.

A loss in net returns of $208,772 was associated with this constraint. This represented just over a 0.5 percent decline in income from the Base Policy Scenario's net returns. The change in returns was caused by the yield penalties on the crops in activity 3. Chemical and nitrogen levels declined because activity 3 was designed with fewer chemicals and lower nitrogen application levels.

20 Percent Reduction Scenario. At a 20 percent reduction, the estimated 15-year total soil erosion was 706,206 tons. The 20 percent reduction constraint for soil erosion completes the substitutions of activity 3 for activity 1 in year 3 and of activity 15 for activity 1 in year 10. Activity 16L partially replaces activity 3 in year 7. In years 3 and 10, soil erosion levels were reduced by 24,187 tons and 99,851 tons, respectively, from the Base Policy Scenario.

Activity 16L represents a completely organic production activity. Cultivation replaces all chemical weed control in this activity. Corn and soybeans were each cultivated three times. Despite an increase in machinery costs and trips across the field, erosion was reduced. This reduction can be attributed to the use of a winter cover crop. Corn and soybean yields in activity 16L were penalized because of the organic nature of the activity and the establishment of a winter cover crop. Net returns continued to decline from the Base Policy Scenario by $516,242, approximately a one and 1.5 percent decline, as the use of activities with penalized yields increased.

30 Percent Reduction Scenario. In addition to the previous production activity changes, the 30 percent reduction in soil erosion requires the substitution of activity 3 for activity 1 in years 1 and 2; the complete substitution of activity 16L for activity 3 in year 7 and for activity 1 in year 15, and the partial use of activity 16L in year 14. Total soil erosion was reduced by 264,827 tons. Net returns were reduced by 5 percent from the Base Policy Scenario to $30,251,652, which was a 3 percent reduction in income.

40 Percent Reduction Scenario. A 40 percent reduction represents the target reduction level suggested by the Chesapeake Bay Agreement. In this study, the 15-year total soil erosion was 529,654 tons. In addition to the previous changes in production activities, the additional constraint on erosion forces the partial use of activity 10 in year 3 and the complete use of activity 16L in years 5 and 14. Activity 10 is similar to activity 16L in that they both use a rotation that includes a winter cover crop. Activity 10 includes a winter rye cover crop. Activity 10 substitutes some mechanical weed control for the elimination of metolachlor from weed control chemicals. Both corn and soybeans were planted no-till in activity 10 and corn was cultivated once.

Total net returns were reduced by over $1,495,000, a 4.8 percent reduction in income from the Base Policy Scenario. All chemical levels in this erosion and in runoff were reduced as was the case in the previous scenarios. However, note with the expanded use of activity 16L, which includes poultry litter as a nitrogen source and a legume winter cover, the level of nitrogen in percolation increased. This was partly due to the slow release of available nitrogen from poultry litter during periods when plant requirements are low. The same factors may be associated with the legume cover crop after it is disked under; i.e., the nitrogen in the roots and residue is slowly released, may not be timed with peak needs of the plant, and, therefore, may be leached.

50 Percent Reduction Scenario. The 15-year total erosion level was 441,379 tons. Reducing potential soil erosion by 50 percent results in the use of the organic activity, 16L, in 7 of the 15 years on all acres and in combination with activity 1 in year 12. Activity 3, a low chemical activity, was used in 3 years on all available acres. All chemical and nitrogen levels were decreased except the nitrogen levels in percolation. This level rose by 1,975,021 pounds from the Base Policy Scenario level. Net returns were reduced by 6.6 percent to $29,121,799.

Conclusions

One of the benefits of low-input production activities is the improvement of soil fertility from reduced erosion and increased organic matter levels and microbial activity. Another benefit is better water quality. This study finds that reduction of soil erosion from conventional levels in Richmond County, Virginia can be achieved by adopting low-input production practices. In particular, activities that reduce deep tillage and use winter cover crops reduced soil erosion substantially. The economic penalty for this change in production activities was 6.6 percent or less, a fairly small reduction for a county-based analysis over 15 years and 32,317 acres of cropland. An additional benefit from controlling soil erosion is the reduction in nitrogen and chemicals carried by sediment to water bodies. Few chemicals appeared in soil erosion in this study; however, atrazine, which does appear, is under restricted use in many areas of the nation. Nitrogen levels in erosion were much higher than chemical levels, and, under the maximum soil erosion constraint of 50 percent, nitrogen was reduced by 67 percent. Soil erosion control may thus contribute significantly to controlling nitrogen contamination of surface water. However, the use of low-input activities that include legumes and animal manures for nitrogen sources may introduce higher levels of nitrogen in percolation. These organic nitrogen sources require special handling and application techniques, so that the available nitrogen is not lost.

The constraints in this model were not on an annual basis but targeted for a time period of 15 years. The annual variability in soil erosion from weather permits the use of soil-conserving production systems in selected years, but not necessarily in all years. When policies target a long-run reduction percentage, such as in this study, the annual variability of erosion can cause only partial adoption of conserving techniques. A longer target period allows transition, experimentation, and flexibility. In this study, activity 12 was an intensive production activity including corn, double-cropped soybeans, and full-season soybeans. In most areas, this activity would be considered environmentally degradating because of the tillage practices and chemical requirements needed to follow soybeans with soybeans. Soybeans also can be detrimental to soil quality. However, this activity appears consistently in 3 of the 15 years in this study. Annual variability in erosion practices allows this activity to remain in these years, despite constraints. Also, activity 12 provides a large contribution to net returns, because soybean prices were relatively high, especially in years 4, 8, and 9.

The results of this study indicate that by controlling soil erosion, nitrogen and chemical levels in the eroded soil, percolation, and runoff also can be affected. Although the low-input practices in this study substituted cultivation for chemical weed control, their erosion levels were lower. However, net returns did fall as more low chemical and organic activities were used. The yield penalties assessed to these activities were based on the best available knowledge but not on controlled field tests. There is a paucity of field information on the use of low-input and organic activities, their yields, and environmental impacts, which challenges researchers in this area.

Soil erosion research and policy have been with us since the Dust Bowl era. However, erosion continues to be a problem, not only because of the suspended soils in and siltation of water bodies, but because of the nutrients and chemicals that travel with the soil. Tillage practices and residue cover historically have been the cores of soil erosion control. New research is needed to relate the ability of low-input or alternative cropping systems, including tillage, cover crops, rotations, and cultivation, to contribute to soil conservation and other environmental benefits such as improved water quality.

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Table 1. Summary description of cropping activities available in the mathematical model.*

Production Activity†	Crop Rotation‡	Chemical/Nutrient Application Level	Chemicals Removed
1,1L	C/SG-DC (2YR)	Medium	None
2,2L	"	High	None
3,3L	"	Low	None
4	"	Medium	None
5L	"	Organic	All
6,6L	"	Medium	Atrazine
7,7L	"	Medium	Metolachlor
17,17L	"	Medium	Paraquat
8,8L	C/SG-DC-Rye (2yr)	Medium	None
9,9L	"	Medium	Atrazine
10,10L	"	Medium	Metolachlor
11L	"	Organic	All
18,18L	"	Medium	Paraquat
12,12L	C/SG-DC/FS/SG-DC (4YR)	Medium	None
13,13L	"	Medium	Atrazine
14,14L	"	Medium	Metolachlor
19,19L	"	Medium	Paraquat
15,15L	C/SG-DC-Mix (2YR)	Medium	None
16L	"	Organic	All

*See Diebel (5). Appendix B.1 for a more detailed description of production activities.
†An "L" with the activity number indicates that poultry litter was used as the source of nitrogen; otherwise, activities with the same number are identical.
‡C=corn;
SG=small grains (wheat and barley);
DC=double-cropped soybeans;
FS=full-season soybeans;
Mix=rye and crimson clover.

Table 2. Summary of the agricultural practices selected under each soil erosion constraint and the 15-year total net returns.

Soil Erosion Reduction Constraint	Total Net Return (1988 dollars)	Production Activity*														
		Year														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Base(0%)	31,199,006	1	1	1	12	3	4	3	12	12	1	3	1	1	3	1
10%	30,990,234	1	1	1/3	12	3	4	3	12	12	1/15	3	1	1	3	1
20%	30,682,764	1	1	3	12	3	4	3/16L	12	12	15	3	1	1	3	1
30%	30,251,652	3	3	3	12	3	4	16L	12	12	15	3	1	1	3/16L	16L
40%	29,703,662	3	3	10/3	12	16L	4	16L	12	12	15	3	1	1	16L	16L
50%	29,121,799	3	3	16L	12	16L	16L	16L	12	12	16L	3	1/16L	1	16L	16L

*See Table 1 for description of activities.

Table 3. Fifteen-year total soil erosion and nitrogen and chemical levels in erosion under each soil erosion constraint.*

Soil Erosion Reduction Scenario	Erosion (tons)	Nitrogen Level in Erosion (lbs)	Nitrogen Chemical† Levels in Erosion (lbs)			Nitrogen Level in Percolation (lbs)
			Atrazine	Metolachlor	Fluazifop -butyl	
Base Policy	882,757	7,202,479	22.9	3.2	30.4	7,020,380
10 percent	794,481	6,757,586	22.5	2.1	29.1	6,426,767
	(-88,276)	(-444,893)	(-.4)	(-1.1)	(-1.3)	(-593,613)
20 percent	706,206	6,111,077	22.2	1.9	27.5	6,737,226
	(-176,551)	(-1,091,402)	(-.7)	(-1.3)	(-2.9)	(-283,154)
30 percent	617,930	4,898,710	21.7	.9	27.2	6,571,487
	(-264,827)	(-2,303,769)	(-1.2)	(-2.3)	(-3.2)	(-448,893)
40 percent	529,654	4,119,264	21.3	.9	17.3	7,392,387
	(-353,103)	(-3,083,215)	(-1.6)	(-2.3)	(-13.1)	(+372,007)
50 percent	441,379	2,368,373	20.7	.6	10.7	8,995,401
	(-441,378)	(-4,834,106)	(-2.2)	(-2.6)	(-19.7)	(+1,975,021)

*The numbers in parentheses are the changes in the values from the Base Policy Case.

†The following chemicals were used but had zero levels in soil erosion under all constraints: paraquat, fenvalerate, trifluralin, glyphosate, acifluorfen, DPX-M6316, chlorimuron, linuron.