Economic and Environmental Impacts of Water Quality Restrictions on Agriculture:

An Application to Cotton Farming

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Abstract

Survey data on cotton agrichemical use were used to assess the consequences of policies to reduce or prevent degradation of water resources from chemicals and sediment. Reducing erosion or restricting chemical use on environmentally risky cropland would raise prices, but could generate environmental benefits by improving water quality.

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»Introduction

In recent years, there has been an increasing amount of attention placed on water pollution thought to be associated with agricultural production. That nutrients, animal wastes, pesticides, and sediment from farmland contribute to the Nation's surface water pollution problem has long been recognized. However, over the past 5 years public policy has shifted significantly toward addressing nonpoint sources of pollution (such as agricultural and urban runoff and leaching to ground water) as well as point sources like municipal and industrial plant discharges. Public concern about the presence of pesticides and nitrates in ground water from the use of agricultural chemicals has risen following some well publicized findings of pesticides and nitrates in drinking water. In response to this concern, many Federal and State agencies have begun to develop programs to prevent possible pollution of ground water by agricultural chemicals.

As part of the President's 1989 Water Quality Initiative, the Economic Research Service and the National Agricultural Statistical Service of the U.S. Department of Agriculture (USDA) conducted a survey of cotton producers in 14 Southern and Western States in 1989. Information from the Cotton Water Quality Survey (CWQS) provides a comprehensive accounting of field applications of pesticides and fertilizers on the 1989 cotton crop. The survey accounted for cotton production practices on 10.5 million acres (99 percent of the total U.S. planted cotton acreage of 10.6 million acres).

Earlier reports have used data from the CWQS to characterize the scope and extent of the potential for cotton production to adversely affect ground and surface water quality (see Crutchfield, et. al., 1991). Using data from the CWQS, previous studies have evaluated the potential for cotton production to contribute to water quality problems. Data on agricultural chemical use and management practices in cotton farming in conjunction with physical data on resource conditions were used to identify the likelihood that cotton farming may contribute to water quality problems. Using several screening models, the surveyed cotton acreage was characterized on the basis of the potential for chemicals and sediment to surface and ground water quality.

Indicators of relative environmental risk were developed using screening models developed by Goss and Wauchop (1990) and Williams and Kissell (1991) to measure the likelihood that herbicides, insecticides, fungicides, nitrogen fertilizer, and other agricultural chemicals applied to cropland would pose a risk of contamination for ground water supplies or that chemicals would leave the filed dissolved in runoff or attached to eroding soil particles. Based on the soil characteristics and the chemical properties of chemicals used, each sample point in the survey was assigned an ordinal measure of the potential for chemicals to leach below the root zone, adsorb to sediment, or wash away in runoff. Table 1 shows the distribution of surveyed cotton acreage across environmental risk classifications. (For complete details on the classification procedure, see Crutchfield, et. al., 1991).[1]

We use this information as a starting point to target a set of input use and farming practice restrictions aimed at preventing agricultural pollution to those areas showing the greatest environmental risk from cotton production. In this report, we evaluate alternative pollution prevention strategies which may be used to reduce the potential for water quality degradation. The strategies are assessed for their environmental effectiveness and for their economic impacts on cotton farmers and consumers through yield losses and price increases. Analytic results highlight the importance of targeting: selective application of input use and farming restrictions to areas with the greatest relative risk of environmental degradation can substantially reduce the economic impact on cotton farmers of these policies.

Analysis of Pollution-Reducing Production Changes on Cotton Cropland

In this section, we assess the likely consequences of restricting cotton farmers' chemical applications to eliminate the use of those pesticides, herbicides, and other chemicals most likely to impair water quality. Specifically, we explore three broad classes of pollution prevention strategies: requiring installing of erosion-reducing farming practices, restricting nitrogen application on cropland thought to be vulnerable to nitrate leaching, and banning the use of pesticides likely to leach or leave the field via erosion and runoff.

Specification of Production Relationships

We start by building a model of cotton production which is to be estimated using data from the survey. The objective is to quantify the relationship between farming practices, chemical input use, and yields obtained by cotton farmers. Doing so will enable us to evaluate the changes in yields, and, therefore, farm revenues as input choices are restricted for environmental reasons.

Our modelling approach is influenced by the nature of the available data. The 1989 Cotton Water Quality Survey (CWQS) randomly sampled acres in cotton producing areas for information on chemical use, production practices, and resource data at each sample point. Each observation, then, gives an estimate of input and yield relevant to that particular acre. Data from the CWQS can be used to estimate input-output relationships. However, certain economic factors cannot be included on a per-acres basis (i.e., al-location of capital and other fixed factors within a farm enterprise). The estimated production relationship, then, is of a partial nature, and does not capture some substitution possibilities (i.e., output-output substitution or land-capital substitution).

To begin with. we assume that the per-acre yield of a cotton field depends on several generic classes of inputs:

(1) $Y = Y(C,W,R,Z)$ where
Y = Yield (bales/acre)
C = Applied chemicals
W = Water (irrigation)
R = Site-specific measures of soil quality
Z = Farm management choice variables.

A variety of functional forms have been used to estimate yields functions. Examples commonly used in empirical studies include the quadratic, Mitscherlich-Baule, and Von Liebig type functions. (Cerrato and Blackmer, 1987; Frank et. al. 1990). We use here a modified version of the quadratic function which was used by Huang and Hansen (1991) to estimate cotton yield responses to nitrogen application using CWQS data. We model cotton production in the following manner:

$$\begin{aligned} (2) \quad Y = {} & a_0 + a_1*N + a_2*N^2 + a_3*W + a_4*W^2 + a_5*W*N \\ & + b_1*WTRCAP + b_2*SLOPE + b_3*PERM + b_4*ORGN + b_5*EROSION \\ & + c_1*IRR + c_2*EC + c_3*CT + c_4*ARP + c_5*HERB + c_6*INSECT + c_7*SEED \end{aligned}$$

where:

N = Nitrogen applied (pounds/acre)
W = Water applied, including estimated rainfall and irrigation water (acre feet/acre)
WTRCAP = Water holding capacity of the soil
SLOPE = Slope of the surveyed field
PREM = Permeability of the soil
ORGN = Organic matter content of the soil
EROSION = Erosion rate (calculated using the Universal Soil Loss Equation)
IRR = Dummy variable for irrigation (1 if field is irrigated)
EC = Dummy variable for erosion control (1 if field had erosion control practices installed)
CT = Dummy variable for conventional tillage (1 = conventional, 0 = reduced or no-till)
ARP = Dummy variable for cotton acreage reduction program (1 if farmer participated in cotton ARP in 1989)
HERB = Herbicides, measured by total pound active ingredient applied per acre.
INSECT = Insecticides, measured by total pound active ingredient applied per acre.
SEED = Seeding rate, pounds/acre.

This particular specification was used to capture anticipated non-linearity in nitrogen's effect on yield, as well as possible interaction between applied nitrogen and water.

Estimation results

The production function (2) was estimated using 1989 CWQS data. After observations with refusals and missing or inappropriate values were thrown out (i.e., reported yield of zero) 1109 observations were available. Equation (2) was estimated using the non-linear least squares (SYSNLIN) procedures in SAS. Results are presented in Table 2.

Overall, the estimated equation showed a good fit: adjusted R-Squared was .57, which is good for cross-sectional data such as this. Four of 19 estimated parameters were not significant at the usual confidence levels of 95 percent (three were insignificant at a 90 percent confidence level).

As anticipated, cotton yields showed decreasing returns in nitrogen and water, although the second order term for nitrogen was fairly small. Our dummy variables for farming practices had the expected signs: ceteris paribus, irrigated farmers had higher per-acre yields, farmers applying erosion control practices had lower yields, and farmers using conventional tillage practices had higher per-acre yields than those using no-till or low-till practices.

Yield Effects of Reduced Nitrogen Use

The estimated production function was used to evaluate the effect of environmental policies aimed at protecting ground water quality. Two specific scenarios were used to reflect these policies: 1) mandated reduction of nitrogen fertilizer application to 100 pounds per acre on land considered vulnerable to nitrate leaching, and 2) reduction of nitrogen application to 75 pounds per acre on vulnerable cropland.

For both scenarios, the estimated regression coefficients were used with actual survey data to predict a baseline estimated yield. Then, a second input dataset was created where the nitrogen application rate was modified according to whether the land was considered to have a high or excessive nitrate leaching potential. This was done for each sample point in the survey, and results aggregated to state, regional, and national levels using expansion factors built into the survey[2]. Predicted yields for each scenario were compared to baseline estimates and percentage yield losses calculated.

The results are presented in Table 3. For the two scenarios considered, overall yield losses (based on total harvested acreage) ranged between 2 percent and 4 percent. Some variation across states and regions is evident, which is to be expected since the distribution of erodible and vulnerable acreage is not uniform across regions. Also, it is worth noting that not all farmers face input use restrictions: nationwide, nitrogen restrictions of 100 pounds/acre or 75 pounds/acre on vulnerable land applied to about 17 percent and 28 percent of all acreage, respectively. As a consequence, the yield losses and economic impacts will not apply to all farmers and all regions.

Yield Effects of Restrictions on Pesticide Use

In this study, we take an alternative approach to estimating the impact of restricting input use. Ideally, we would like to model agricultural chemical use by estimating a cost or production function based on existing data using an econometric or programming approach. The effects of restricting either quantities or imposing taxes could then be simulated, yielding not only changes in output but changes in input mix as well (for instance, substitution of labor or land for restricted agricultural chemicals).

This approach is not feasible or particularly useful for analyzing the types of issues which concern us here, for a variety of reasons. First, the range of input choices regarding agricultural chemicals used in cotton production is quite broad: the survey listed nine dessicants or defoliants, eight fungicides, three growth regulators, thirty herbicides, and fifty two insecticides. Collinearity problems and loss of degrees of freedom (not all chemicals are used by all farmers) would preclude listing all 102 possible chemical choices as right-hand-side variables in a production or cost function. When we constructed our simple yield function, we therefore aggregated pesticides into distinct categories (herbicides and insecticides)

However, treating pesticides aggregated by classes is not going to help us assess the types of input restrictions which are imposed to protect water quality. US EPA policies aimed at pollution prevention are targeted at specific chemicals, often in specific areas or in specific uses. It is most unlikely that farmers are going to be faced with restrictions on "insecticide" or "herbicide" use; rather, water quality policies take the form of restricting individual chemicals, which are identified, based in part, on their expected propensity to leach or enter surface water bodies.[3] We need, then, to determine the ability of farmers to substitute pesticides and the associated impacts on yields and costs on a chemical-by-chemical basis.

As an alternative to explicitly incorporating chemical-specific input substitution possibilities in our econometric model, we drew instead upon expert opinion from participants in a cotton chemical use assessment study (see USDA Pesticide Assessment of Cotton, 1991) to understand how losses of specific chemicals would affect cotton production and input use. Experts estimated the pesticide materials, control practice, and acreage treated for each reported target pest on a state-by-state basis (USDA Agricultural Research Service, various years.) Also included in the assessment were three critical pieces of information: a listing of alternative chemicals if the pesticide in question were "lost," an estimate of potential yield loses if substitute chemicals were used, and an estimate of potential yield losses if the substitute chemicals were also "lost" or not available. The last element is crucial: it might be the case that if one pesticide were banned due to its susceptibility to leaching, adsorption, or runoff an important alternative might also be highly leachable, and therefore not available to farmers under a policy to restrict use of leachable chemicals. Therefore, we need estimates of yield losses if alternatives to regulated chemicals are not available for use.

Our methodology, then, was to use this expert information about substitution possibilities and potential yield losses to construct estimates of chemical use, vulnerability, and yield per acre on the survey data under a number of different chemical regulation scenarios. A synthetic dataset was created which contained estimates of per-acre yields and chemical use, based on the information in our expert opinion surveys on likely chemical substitutions and yield losses.

A critical assumption here is that all other factors of production were held constant in the presence of chemical use restraints. This, of course, does not accommodate the possibility of farmers changing other inputs (land, labor, crop rotations, etc.) in response to restrictions on chemical applications. We are forced to make this admittedly arbitrary assumption owing to the absence of any quantitative information about substitution of non-chemical for chemical inputs on a chemical-specific basis, either from our model of cotton production or expert opinion. In defense of this assumption, however, we noted in our analysis of qualitative information from the expert opinion surveys that in most cases alternatives to restricted chemicals were available, so farmers could protect yields somewhat by making marginal adjustments in their choice of chemical mixes applied to cotton acreage. This would imply that the bias introduced by not explicitly accounting for non-chemical alternatives to banned pesticides may be minor.

To assess the impact of pollution prevention strategies, we first drew up a list of likely candidates for chemical restrictions; those chemicals listed in the SCS/ARS/CES Pesticide Properties Database (Goss and Wauchop, 1991) as having "Large" potential for leaching, adsorption, or loss in runoff. At each sample point on the Cotton Water Quality Survey, a computer simulation model examined the range of chemicals used on that sample field. If, at that sample point, a chemical was used which had a "Large" potential for leaching, the expert opinion database was queried to determine potential alternatives to the pesticide in question. Those alternative chemicals not considered environmentally risky (i.e., "Large" potential for loss from the field) were substituted for the chemical in question at that sample point, with estimates of application rates and number of treatments based on the target pest and recommendations drawn from the expert database. A new estimate of the per-acre yield was also constructed, based on expert opinion of the likely yield impacts if the chemical in question were "lost." If no alternatives to the chemical in question were available (either none listed in the expert database, or none available which had "Low" or "Moderate" loss potentials,) then the chemical in question was deleted from the input dataset and the sample point yield estimate adjusted to reflect the "no alternatives available" adjustment factor from the expert opinion database.

Table 3 also presents the predicted yields from surveyed acreage from the two pesticide use policy options considered.[4] Overall, when "risky" chemicals (those thought to leach or leave cropland through runoff or adsorption to sediment) are banned nationwide yields fell by about 1.6 million bales, or 14.5 percent. If "risky" chemicals are banned ONLY on acreage identified as having the highest potential for pesticide loss, yield losses were smaller: about 560,000 bales, about 5.7 percent. This is due to the fact that only about half the cotton acreage was thought to be at risk for some form of pesticide loss (see Table 1).

Environmental Impacts of Modified Production Practices: Erosion Control and Conservation Tillage.

The suspended sediment model developed by Ribaudo was used to estimate the potential improvements in surface water quality if erosion on cotton acreage were reduced. This involved a two-step procedure. First, potential reductions in erosion on cotton cropland were estimated for the two scenarios described above: installing conservation practices on highly erodible acres and reducing erosion on cotton acreage via conservation tillage. The reductions in erosion were then fed into the model to predict the changes in concentrations of suspended sediment for regions covered by the survey.

The first scenario assumed that farmers adopted conservation tillage practices on land considered "highly erodible" under the standard used for the conservation compliance provisions of the Food Security Act of 1985. A comparison was made of erosion occurring in the base case (current patterns of conservation tillage use) and the erosion that would occur if reduced tillage practices were applied on cotton acreage labeled "highly erodible". The results indicate that erosion would decrease by about 14 percent.[5] Average erosion rates would decrease from 5.3 tons/a/y to 4.6 tons/a/y.

The second scenario assumed that operators farming highly erodible land installed erosion control practices, such as terracing, contour farming, and strip cropping. Erosion rates were calculated on the assumption that such practices were adopted on highly erodible land. The results indicate that erosion would be decreased by about 19 percent. Average erosion rates would decrease from 5.3 tons/a/y to 4.3 tons/a/y. Erosion rates in several states, notably Arkansas and Alabama, remained high despite the installation of conservation practices on highly erodible land.[6]

The changes in erosion rates from these two scenarios were then used to estimate the expected changes in surface water quality. A baseline level of suspended sediment was calculated from 1982-83 monitoring data. The effects of reduced erosion from switching away from conventional tillage and from installing erosion control practices were measured by the changes in concentrations of sediment in these watersheds. The results indicate that reducing erosion on cotton acreage alone would not greatly improve surface water quality regarding sediment loadings, even if the erosion reductions on cotton acreage are substantial. The reason is that there are many sources of sediment in surface water besides cotton cropland, and the contribution from cotton in any one region is not great.

Economic Impacts of Environmental Policies

Environmental policies aimed at preventing water pollution will have an economic impact on cotton farmers and society as a whole. Restrictions on input use may raise production costs. Prices and support payments may be affected if alternative environmental policies reduce cotton harvests. The increased costs of production and the increased prices paid by consumers after the imposition of environmental controls represent a net economic cost to society for the gain in water quality.

On the other hand, society values clean water. Reducing sedimentation or other impairments in lakes and streams can generate significant benefits in recreational and other uses (Clark et. al. 1985, Ribaudo 1986). If the value placed by society on the gain in water quality exceeds the cost to consumers and producers of reducing the pollutant loadings, net social welfare increases.

Valuing economic impacts on the production side is fairly straightforward. When yield are reduced, market prices may increase, causing shifts in production and consumption. We use the U.S. Agricultural Resources Model (USARM) to quantify the expected price, production, and output effects of several policies for pollution prevention. Estimated changes in prices and incomes under the alternative environmental policies are used to measure the differential effects these policies may have on the agricultural sector.

Valuing the environmental benefits of improving or protecting water quality is more problematic. Ribaudo (1989) has developed a model which links changes in on-farm practices to off-farm benefits due to water quality improvements from reduced soil erosion. We use this model to value the improvement in surface water quality associated with reducing erosion and installing conservation measures on highly erodible cotton cropland.

The economic benefits of protecting ground water quality are less clear. It is beyond the scope of this study to establish a clear linkage between on-farm chemical use and quality of ground water resources. Models such as NLEAP or PRZM could be applied at each sample point to measure chemical losses below the root zone, but we would still need additional information on ambient ground water conditions to measure the change in resource quality, and, eventually, consumer willingness to pay for improved water quality. At present we do not have enough detailed information about ground water quality and its relationship to production practices on cotton cropland to make any but the most general statements about the value of preventing ground water contamination. Accordingly, we use here a cost-effectiveness approach highlight the economic consequences of pollution prevention. We compare the economic impacts of different levels of agricultural chemical use restrictions to prevent leaching; and use differential impacts of these policies to highlight the opportunity costs of choosing different levels of protection for ground water resources.

Economic impacts on cotton producers

The estimated yield impacts of the six alternative policies reported in Table 3 form the starting point for our analysis. For each scenario, we calculate the expected impacts on the agricultural sector using the USARM model. The U.S. Agricultural Resources Model (USARM) is a partial equilibrium, comparative static programming model that simulates competitive equilibria in the presence of deficiency payment programs. (Ervin, et. al.) It is designed to study the likely impacts of changes in resource constraints, prices, and policies on the location, production, and prices of the principal crops, agricultural resource use, and program participation. USARM produces medium-term estimates of these impacts rather than long-term forecasts.

The objective function is quadratic in both revenues and cost. Negatively sloped product demand curves allow output prices to be endogenous at the national level. Positively sloped supply curves impose decreasing returns with rising production of a given activity. The production function is characterized by Leontief technology.

USARM encompasses 9 crops (barley, corn, cotton, hay, oats, rice, sorghum, soybeans, and wheat) and land in the Conservation Reserve Program (CRP) across 23 regions (17 western states plus the 6 eastern Farm Production Regions). The primary decision variables are 1) crop selection and acreage allocation; 2) production method (irrigated or dryland); and 3) participation and non-participation in federal commodity programs.

To simulate the impact of environmental restrictions on cotton production, the state-by-state percentage changes in yield for each of the policy scenarios are used as constraints on the USARM model. That is, yield is restricted in each state to reflect the estimated yield reductions associated with each scenario. The model then solves for equilibrium values of the decision variables by shifting acreage and crop mix across states and regions until the objective function is maximized.

Table 4 presents selected results from the 6 policy scenarios analyzed with the USARM model. As expected, the policy that had the largest yield decline (banning all "risky" chemicals on all cropland) showed the most pronounced effect on prices: a 14.5 percent yield decline led to a 31 percent increase in cotton prices. For most of the other scenarios, the effect on prices and incomes of cotton farmers was fairly small.

The direction of change in cotton farmer's income depended upon the policy in question. The USARM models uses linear demand functions for commodities; therefore, as harvests change the direction of the change in income will depend upon the position of the magnitude of the movement from the initial point along a linear demand curve. Small decreases in yields will lead to declines in net income; for larger harvest reductions we move into the inelastic portion of the demand curve and income rises. For small changes in yields, revenues to cotton farms dropped between $3 and $18 million. When more drastic yield reductions were imposed, price increases offset the decline in output, and income rose by more than $400 million.

It is important to remember, however, that there will be distributional effects associated with each scenario. Recall from our earlier discussion of how vulnerability of cropland to erosion or chemical loss was distributed unevenly across all surveyed acreage. Only those farmers who use "risky" chemicals on vulnerable acreage, or who apply high rates of nitrogen, or whose cropland is erosive and is farmed with conventional tillage will be affected by these restrictions. Other farmers for whom the constraint is not binding may enjoy some transient benefits in the form of higher prices for their harvests.[7] Unfortunately, a complete analysis of this phenomenon is not possible, since USARM by its design imposes uniform yield reductions across an entire production region. At present, we don't have the level of temporal or spatial disaggregation in our models to be able to trace through all the distributive impacts of these policies.

In addition, consumers of cotton products will be faced with higher prices if harvests fall. This will mean a loss of consumer surplus, part of which takes the form of a transfer to farmers who receive higher incomes. As an example of this, assume for the moment a linear demand curve for cotton (as is the case with USARM). For the option where environmentally risky chemicals were banned on all cropland, which shows a net increase in farmers' income of $413 million dollars, there is a loss of consumer's surplus of $989 million, with a deadweight loss of about $77 million. The net losses for the most of the other scenarios would be much smaller, but still must be considered in evaluating the overall economic impact of production restrictions.

Water Quality Benefits

For two scenarios (installation of erosion control measures and conservation tillage) we estimated the economic benefits of reduced erosion on cotton acreage to several different categories of water uses: recreational fishing, navigation, water storage, irrigation ditches, roadside ditches, water treatment, municipal and industrial water use, and stream cooling. The procedures for estimating benefits incorporated the physical, chemical, hydrologic, and economic links between the movement of soil and chemicals on the field and the effects on downstream water users.

Benefits per ton of soil erosion reduction were estimated for navigation, water storage, irrigation and roadside ditches, municipal and industrial water use, and stream cooling in each region using data from Clark et. al. and Ribaudo. The reductions in erosion estimated for each scenario were then used to calculate total benefits in these categories.

We estimated the effects of improved water quality on recreational fishing activity with a fishing participation model (Ribaudo and Piper 1991). The model was estimated with recreational data from the U.S. Fish and Wildlife Service's 1980 National Survey of Hunting, Fishing, and Wildlife-Associated Recreation and water quality from the U.S. Geologic Survey's NASQUAN reporting system. The model predicts changes in the number of persons fishing and in the number of days they fished when regional water quality changes. Watershed-level water quality changes from table 10 were used to predict changes in recreational fishing and the economic value of the increase in the recreational activity.

A model of water treatment costs developed by Holmes (1987) helped us estimate changes in the costs of municipal water treatment form reductions in turbidity. The model specifies water treatment costs as a function of turbidity, the amount of water treated and the costs of other inputs. We assumed that water quality is a perfect substitute with other turbidity-reducing inputs in the treatment process, and that the change in treatment costs does not affect the output of treated water. Benefits, therefore, equal the reduction in the costs of treating water (Freeman 1982). Water quality changes expected with the erosion reduction scenarios were fed into this model to predict the benefits of reduced water treatment costs.

The estimated water quality benefits associated with the two erosion reduction scenarios range between $17.5 (requiring conservation tillage) and $23.5 million (requiring erosion reduction), with most of the benefits accruing to the Delta, Mountain (Arizona and New Mexico), and Southern Plains regions. The average benefit per acre of cropland treated is slightly more than $10 per acre, and ranges from a low of $5 per acre in the Southern Plains to $76 per acre in the Mountain States for installing erosion control measures. In all regions, payments of up to $5.00 per acre for these conservation practices on cotton cropland through some form of cost-sharing or other financial assistance would generate off-farm water quality benefits in excess of costs.

Conclusions

Our objectives in this study were to characterize the scope of the potential water quality problems associated with cotton production, and the economic effects on producers and consumers of strategies to reduce or prevent water pollution from cotton farming. Efforts to prevent these types of pollution by limiting nitrogen fertilizer applications or restrict use of soluble pesticides are expected to have some economic impact by reducing yields and raising cotton prices. When the off-farm benefits of improved water quality from erosion control are considered, the economic benefits from improving water quality are likely to be less than the cost to farmers or society of installing erosion control practices on highly erodible cropland.

Although our ability to quantify the benefits of preventing ground pollution is less developed than our ability to measure the benefits of surface water quality improvement, results generated here do highlight the importance of targeting pollution prevention programs to attain the most cost-effective environmental protection strategies. Applying chemical use restrictions only on acreage classified as susceptible to water quality problems can achieve nearly the same level of reduction in overall vulnerability as when chemical restrictions are applied to all acreage. By targeting chemical use restrictions, yield losses are reduced by over 1 million bales and smaller increases in cotton prices result.

There are some limitations with the data and analytic methods used in this study. Our screening and assessment procedures present only a general characterization of the eventual environmental impacts of cotton farming. Since environmental problems, particularly ground water leaching, are location specific, aggregate measures of leaching, runoff, or erosion potential such as ours inevitably mask considerable localized variability. The characterization of substitution possibilities regarding agricultural chemicals, which is based on expert opinion, may over- or understate the true substitution possibilities by a considerable amount. Finally, since we do not presently have data on ground water quality at a level of detail sufficient to establish a linkage between chemical use and eventual costs to consumers of impaired ground water quality, we compare policies to reduce or prevent leaching on the basis of cost effectiveness, rather then on the ultimate welfare to users of protecting groundwater quality. Additional research into using process models to estimate chemical leachings and changes in water quality, in conjunction with studies on the willingness to pay for reduced exposure to chemicals in drinking water, could improve our estimate of the benefits of preventing ground water pollution.

Finally, it should be noted that cotton is only one of many agricultural products whose production can affect environmental quality. Reducing erosion or chemical use on cotton farms alone may not yield significant water quality improvements if other crops within a given area also contribute substantial pollutant flows to water resources. In addition, it is likely that any policies to prevent pollution, either through voluntary adoption of new management practices or regulations restricting input use, will apply to several crops.

Notes

[1]It should be emphasized that both the pesticide and nitrate screening procedures establish only an indication of potential chemical losses from the root zone and do not quantify or estimate the actual losses of pesticides or nitrates to ground water. Actual leaching to ground water occurs only to the extent that the chemicals applied fail to be taken up by the plant or fail to bind to soil particles in the upper layers of soils. Nitrate and pesticide leaching are site-specific; hot spots and less vulnerable areas will occur within each region, and aggregate measures such as those used here can mask considerable intra-regional variation in leaching potential.

[2]Predicted yields under the baseline scenario were lower than actual yields, since there were several hundred observations with missing values of one or more independent variables. The contribution of those sample points to total acreage and estimated total yield were thereby dropped from the calculations.

[3]For example, EPA's recently released "Agricultural Chemicals in Ground Water Strategy" calls on the states to restrict or ban pesticide use on a chemical-by-chemical basis, when concentrations of chemicals detected in ground water reach a certain percentage of maximum allowable levels. These restrictions would most likely be for a defined geographic region (such as a wellhead or critical recharge zone) or for specific uses or application methods rather than wholesale, state- or nation-wide use restrictions.

[4]Since the survey is field based, yield estimates for each sample point reflect the number of bales per harvested acre at that point. Weighting factors developed as part of the survey are use to aggregate up to national yield estimates on all 10.2 million acres.

[5]Not all acres in the survey were assessed. Unassessed acres were deleted and the results were adjusted to reflect the full base acreage. Since assessment was uneven between States, comparison between States may not be representative.

[6]This scenario implicitly assumes that farmers harvesting on highly erodible lands would, in fact, install conservation measures on that cropland. In practice, farmers may choose to forgo participation in USDA programs rather than install such practices if the costs of conservation outweigh the benefits of program participation.

[7]The USARM model treats all cropland within a state uniformly, and so is not able to distinguish between vulnerable/erosive cropland and cropland not subject to input constraints.

Table 1 - Distribution of Environmental Risk

(1,000 acres by loss potential category)

	Potential for Pesticides Applied to Cropland to Leave the Field: Via Leaching		Attached to Sediment		Dissolved in Runoff		Potential for Nitrogen to Leach Below the Root Zone		
	Acres	%	Acres	%	Acres	%		Acres	%
Potential 1	491	5	5,103	50	2,649	26	Excessive	1,915	19
Potential 2	2,161	21	1,449	14	3,787	37	High	2,653	26
Potential 3	3,636	36	429	4	545	5	Moderate	1,827	18
Potential 4	1,679	17	N/A		N/A		Low	2,761	37
Unknown	2,192	22	3,177	31	3,177	31			

Note: Potential 1 indicates highest relative risk of pesticide loss from leaching or runoff/adsorption, while potentials 3 and 4 indicates little or no likelihood of pesticide loss via runoff/adsorption or leaching, respectively.

Table 2 - Production Function Estimation Results

Nonlinear OLS Summary of Residual Errors
SSE: 373.12528 MSE 0.34232 Root MSE: 0.58508
R-Square: 0.5811 Adj R-Sq: 0.5742

Nonlinear OLS Parameter Estimates

Param.	Estimate	Std Err	Approx. 'T' Ratio	Approx. Prob > |T|	Label
A0*	1.257840	0.16540	7.60	0.0001	
A1*	0.00488686	0.0005629	8.68	0.0001	Nitrogen
A2*	-9.88097E-6	1.58692E-6	-6.23	0.0001	Nitrogen squared
A3*	0.400762	0.03825	10.48	0.0001	Water
A4*	-0.041023	0.0049209	-8.34	0.0001	Water Squared
A5*	0.00038533	0.000123[illegible]	3.12	0.0018	Water*Nitrogen
B1	0.033203	0.63308	0.05	0.9582	Water Capacity
B2	-0.021952	0.01428	-1.54	0.1245	Slope
B3*	-0.00070464	0.0002873	-2.45	0.0143	R Factor
B4*	-0.021758	0.0088866	-2.45	0.0145	Soil Permeability
B5*	-0.068709	0.02864	-2.40	0.0166	Organic Matter Content
B6	0.00037546	0.0009511	0.39	0.6931	Erosion from USLE
C1*	0.119543	0.05640	2.12	0.0343	Irrigation Dummy
C2*	-0.097359	0.04774	-2.04	0.0417	Erosion Control Dummy
C3*	0.138306	0.06862	2.02	0.0441	Conventional Tillage Dummy
C4*	-0.128535	0.06343	-2.03	0.0430	Particip. in Cotton ARP
C5**	0.013009	0.0079039	1.65	0.1000	Herbicides (lbs AI/acre)
C6*	0.044826	0.0080004	5.60	0.0001	Insecticides (lbs AI/acre)
C7*	-0.016397	0.0043422	-3.78	0.0002	Seed

*Significant at a 95 percent confidence level.
**Significant at a 90 percent confidence level.

Table 3 - Yield Losses from Chemical Restrictions

(Yields in 1,000 bales)

		Limit N to 100 lbs/acre on Vulnerable Land		Limit N to 75 lbs/acre on Vulnerable Land		Require Erosion Control on Erodible Land		Require Cons. Tillage on Erodible Land	
	Base Yields	New Yield	Pct. chg.	New Yield	Pct. chg.	New Yield	Pct. chg.	New Yield	Pct chg.
Delta	3,063	3,004	-1.9	2,907	-5.4	3.046	-0.5	3,026	-1.2
Southeast	651	640	-1.7	622	-4.7	647	-0.6	641	-1.5
Southern Plains	4,243	4,225	-0.4	4,211	-0.8	4,141	-2.4	4,039	-4.8
West	2,492	2,366	-5.0	2,298	-8.4	2,483	-0.3	2,479	-0.5
All Regions	10,449	10,235	-2.1	10,037	-4.1	10,317	-1.2	10,185	-2.3

		Restrict "Risky" Pesticide Use on All Cropland		Restrict "Risky" Pesticide Use on Vulnerable Land	
	Base Yields	New Yield	Pct. chg.	New Yield	Pct. chg.
Delta	3,864	3,442	-11.0	3,714	-4.0
Southeast	1,017	644	-35.6	995	-2.2
Southern Plains	3,120	2,699	-14.0	2,787	-11.0
West	3,284	2,875	-13.0	3,228	-2.0
All Regions	11,284	9,651	-14.5	10,724	-5.0

Table 4 - Economic Impacts of Environmental Restrictions.

	Acreage**	Pct. chg.	Price***	Pct. chg.	Yield****	Pct. chg	Total Income*****	change[4]	Change in Consumers Surplus[4]	Deadweight Loss[4]
Base Case	10,032		0.637		11,284		3,450,196			
Conservation Tillage on Erodible Acreage	10,001	-0.3	0.642	0.8	11,137	-1.3	3,431,978	-18,218	26,905	176
Erosion Control on Erodible Acreage	9,964	-0.7	0.647	1.6	11,002	-2.5	3,416,781	-33,415	53,486	677
Limit N to 100 lbs/Acre on Vulnerable Cropland	10,004	-0.3	0.650	2.0	11,047	-2.1	3,446,664	-3,532	69,673	739
Limit N to 75 lbs/Acre on Vulnerable Cropland	9,951	-0.8	0.676	6.1	10,844	-3.9	3,518,661	68,465	207,118	4,118
Restrict "Risky" Chemicals on All Cropland	8,975	-10.5	0.834	30.9	9,651	-14.5	3,863,488	413,292	989,807	77,208
Restrict "Risky" Chemicals on Vulnerable Cropland	9,764	-2.7	0.679	6.6	10,724	-5.0	3,495,166	44,970	221,841	5,645

Notes

** 1,000 Acres
*** Cents per pound
**** 1,000 Bales
***** 1,000 Dollars

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