The Adoption of Best Management Practices to Reduce Agricultural Water Contamination

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Abstract

Nonpoint source water pollution generated by agricultural production is considered a major environmental issue in the United States and Europe. One strategy in the United States has been to adopt various measures, called best management practices (BMPs), to reduce water pollution. Our research addresses legal institutions and the applied use of BMPs, and discusses compensatory payments to reduce nitrogen fertilization levels. Models employed in Georgia and Baden-Wuerttemberg evaluate institutional constraints of payments to reduce nitrogen usage, penalties for excessive leaching, and financial incentives for meeting minimum mineralized nitrogen levels. By modeling net returns, preferred economic strategies for producers are identified. Results show that while BMPs can reduce agricultural nonpoint contamination, pollution abatement may be costly to producers. Thus, reduced pollution probably will require some type of government intervention.

1. Introduction

In developing strategies for the optimal use of the resources of the Baltic Sea, consideration must be given to nonpoint source water pollution generated by agricultural production. While various changes in the agricultural resources and production of the Baltic region make it difficult to discern the amount of pollution generated by this sector of the economy, it is well documented that animal production and the heavy use of fertilizers on agricultural crops produces excess nitrogen that moves into the waters of the Baltic Sea. Our paper addresses the issue of agricultural water contamination and strategies that might be employed to reduce the amount of nutrient pollution by agricultural facilities.

Pollution of water by agriculture may be categorized into three major groupings: erosion, nutrients, and pesticides. Although these groupings are distinct and may present different problems, each pollution issue contributes to the public's concern of water quality. One approach has been to adopt various measures to reduce water pollution, and best management practices (BMPs) have received considerable attention in the United States (U.S.). BMPs generally refer to practices determined to be the most effective practical means for preventing or reducing the amount of pollution generated by nonpoint sources to a level compatible with quality goals (CENTNER et al.). The U.S. Environmental Protection Agency (EPA) defines a BMP as "[m]ethods, measures or practices selected by an agency to meet its nonpoint source control needs" (Code of Federal Regulations 1994). BMPs include structural and nonstructural controls and operation and maintenance procedures. BMPs can be applied before, during and after pollution-producing activities to reduce or eliminate the introduction of pollutants into receiving waters. In theory, BMPs minimize water pollution through the application of conservation principles that are ecologically sound.

This article addresses research in the United States and Germany concerning the use of BMPs, with an emphasis on nitrate pollution. Section two identifies the legal institutions of the United States which directly relate to BMPs. In the third section, BMPs prescribed for use in the state of Georgia are described. Next, the economics of management practices and incentives in controlling agricultural water pollution are discussed. The fifth and sixth sections summarize findings from a pilot project conducted in Georgia and a collaborative research study in Baden-Wuerttemberg, Germany, that were aimed at reducing nitrate pollution. The final section summarizes findings of the paper and presents conclusions and implications on agricultural water quality policies.
2. U.S. Legal Institutions

Several major legal institutions in the United States consisting of laws, regulations and recommendations provide for the use of BMPs to reduce pollution. The Clean Water Act articulates federal requirements for nonpoint source management programs to attain or maintain applicable water quality standards for navigable waters (United States Code 1988). Reports by each American state identify significant nonpoint sources of pollution that denigrate applicable water quality standards or the goals of the Act (United States Code 1988). States have developed processes for identifying BMPs and measures to control nonpoint sources of pollution, and they have identified state and local programs for controlling pollution emanating from nonpoint sources (United States Code 1988). The federal government appropriated funds for projects to control nonpoint source pollution (United States Code 1988) but did not mandate the use of BMPs in the Clean Water Act.

States have adopted nonpoint source management plans pursuant to the federal Clean Water Act. Georgia adopted its plan in December, 1989, and the Georgia Soil and Water Conservation Commission (Commission) was designated as the administering agency for the management of agricultural nonpoint sources of pollution (Environmental Protection Division 1989). The Commission conducted a statewide program to encourage the voluntary adoption of BMPs and reported its findings and a list of BMPs. The subsequent publication of updated findings and recommendations occurred in 1994 (Georgia Soil & Water Conservation Commission 1994). Further state legislation delineates additional information on BMPs (Georgia Code Annotated 1994; Georgia Compilation of Rules & Regulations 1992).

Other provisions impact the use of management practices to reduce agricultural pollution. Because regulations of the Clean Water Act classify concentrated animal feeding operations as point sources of pollution (United States Code 1988), these operations are governed by other provisions. The Federal Insecticide, Fungicide, and Rodenticide Act (United States Code 1994) governs pesticides, and various regulations impact the use of pesticides that pollute water (Code of Federal Regulations 1994). The Safe Drinking Water Act established maximum contaminant levels for various contaminants, and states were required to develop wellhead protection programs (United States Code 1988). The Coastal Zone Management Act of 1972 directed coastal states to submit a program with management measures for nonpoint source pollution (United States Code 1993). Management measures under the Coastal Zone Management Act differed from BMPs and are intended to include only economically achievable measures.

Individual state tort law also may be used to address groundwater pollution problems. New regulations concerning liability for pesticide pollution have been adopted in some states (Georgia Code Annotated 1994; Iowa Code Annotated 1993; Vermont Statutes Annotated 1995). The significance of this legislation is that if agricultural producers have not done anything wrong in their use of registered pesticides for agricultural production, then they should not be liable for damages when the pesticides enter groundwater and cause pollution injuries (CENTNER & WETZSTEIN 1992).

3. Pollution Reduction through Best Management Practices

Research pursuant to the Clean Water Act has guided the identification of BMPs to reduce water pollution from agricultural and other land-disturbing activities. Current research continues to suggest new and improved practices that assist in nonpoint source pollution abatement. This section highlights 14 different agricultural BMPs which have been prescribed for protecting water quality in Georgia. Each of these practices is presented under the primary pollution problem that each addresses: erosion, pesticides, and nutrients.

Although BMPs may be beneficial in reducing nutrient and pesticide pollution, a majority primarily address erosion. BMPs for erosion include: (a) cover crops, (b) contour farming and terracing, (c) conservation tillage, (d) streamside vegetative buffers, (e) filter strips and waterways, (f) pasture management, (g) stripcropping, and (h) stream and waterbody protection (Georgia Soil & Water Conservation Commission 1994). Secondary applications of many of these BMPs to one or more other sources of pollution is likely in a systems approach to mitigating water quality impacts. Cover crops of grasses, legumes or small grains are planted to protect or improve the soil. The benefits often involve a vegetative cover to preclude soil erosion in the absence of the main crop and the incorporation of their residues into the soil. Cover crops may be especially important after a low-residue producing crop, such as soybeans or corn cut for silage.

As a BMP, contour farming and terracing are grouped together. Contour farming across the slope on or near the level, as opposed to up and down the slope, is most suitable on uniformly sloping fields. Terraces are earthen embankments constructed on the contour or across a slope to intercept runoff. Expensive to construct, terraces cannot be used on sandy, stony, or shallow soils (Georgia Soil & Water Conservation Commission 1994).

No-till and conservation tillage has gained acceptance as a major agricultural practice to reduce soil erosion and to conserve moisture. Conservation tillage may be defined as a tillage method for planting that leaves at least 30% of the soil surface covered with crop residue (Georgia Soil & Water Conservation Commission 1994). Adoption of this practice often requires an increase in the use of herbicides.

Trees, woody shrubs, and other vegetation can be planted or maintained adjacent to and upgradient from streams and water bodies as vegetative buffers. The streamside vegeta-
tion provides a natural filter for sediment and organic material and their attached nutrients, pesticides and other pollutants.

In areas where it may be expected there will be a shallow and uniform flow of water over a broad surface, filter strips of grass may be used to remove sediment or other pollutants from the runoff. Strips are often about 8 m in width, and grading is usually needed to create a broad area for the uniform flow of water (Georgia Soil & Water Conservation Commission 1994). Similarly, grassed waterways are permanent drainage ways of perennial grasses to protect soils from erosion by concentrated water flows. If livestock are allowed to graze these areas, they must be limited to periods when soil moisture is low enough to preclude compaction, bogging, or the destruction of the vegetation. Ongoing research seeks to determine whether grass buffer strips may cleanse wastes applied via overland flow.

Pasture management involves the selection of plant species, stocking rates, nutrient application, control of weeds, and grazing management (Georgia Soil & Water Conservation Commission 1994). Appropriate planning and implementation of stream and water body protection policies may be important in protecting and enhancing the quality of water, due to potential erosion and pollution caused by livestock. This may include the exclusion of livestock from streams or bodies of water and preventive measures to keep pesticides, fertilizers, animal manures, and other pollutants out of water. For some areas, seed may be drilled or cast to augment existing pastures.

Stripcropping involves the planting of a strip of a sod or close-growing crop with an alternate strip of a row crop. Erosion may be reduced, and the use of rotating crops on the strips may reduce the amount of pesticides needed through this practice (Georgia Soil & Water Conservation Commission 1994).

Practices and preventive measures, such as fencing cattle out of streams, the construction of culverts, the development of sediment basins, or the creation of alternative water sources for livestock form another BMP. Agro-forestry practices to reduce nutrient mobility and to deter pollutants and sediment from entering streams and water bodies, such as filter strips, grassed waterways, and streamside vegetative buffers, also are BMPs that protect water bodies.

Reduction of pesticides may occur through the adoption of pest management programs or crop rotation. One of the most celebrated developments in pesticide pollution abatement has been the development of integrated pest management programs. Through practices and strategies, such as the use of field scouting and data collection and analysis, pesticides are only applied at critical times of need. This BMP thereby lessens the quantities of pesticides used. Research on farm management systems and pest management information may lead to a substantial reduction in the pollution from pesticides. Practices involving chemical mixing sites and rinse pads, as well as careful container disposal, may also form pest management BMPs that are important in reducing pesticide contamination.

Crop rotation through a planned sequence of changing the crop grown on a particular field enables producers to control some pests, diseases, and weeds without the use of pesticides (Georgia Soil & Water Conservation Commission 1994). Rotation may also create different types of residues and better soil quality. For example, a legume may enhance soil nitrogen for a subsequent crop.

BMPs to reduce pollution from nutrients are (a) nutrient management, (b) irrigation water management, (c) agricultural waste management systems, and (d) composting. The two nutrients that are most often associated with agricultural nutrient pollution are nitrogen and phosphorus. Research concerning amounts, sources, forms, placement, and timing of nutrient applications has enabled agricultural producers to engage in application management to control nutrient pollution.

Nutrient pollution may also be reduced due to improved irrigation water management. By controlling the rate, timing, and amount of irrigation water, producers are able to reduce the leaching of nutrients (Georgia Soil & Water Conservation Commission 1994). Technology, such as check valves and anti-syphon devices, may be used to prevent well pollution when fertigation (the application of fertilizer with irrigation) or chemigation (the application of pesticides or chemicals with irrigation) is used.

Facilities and procedures used to temporarily store manure and other waste products for timely application to agricultural land comprise the BMP of agricultural waste management systems (Georgia Soil & Water Conservation Commission 1994). Liquid manure stored in lagoons and slurry manure in waste storage structures are major components of animal production waste management systems. Facility design, procedures, and application of agricultural wastes is also part of this BMP.

Livestock facilities with organic wastes, such as animal manures and dead poultry, may need to adopt a composting process. The process may stabilize the organic matter, reduce odors, preserve nutrients, and prepare the matter for handling or spreading. Composting, with land application at an appropriate time, allows wastes to be utilized on-farm as a soil amendment and a nutrient source of nitrogen (Georgia Soil & Water Conservation Commission 1994).

4. Adoption of BMPs in the United States

The literature on controlling water pollution from agricultural practices takes the non-point nature of this pollution as its element of departure from other literature on pollution control and instrument choice. It is generally accepted that soil loss, nutrient loadings, or pesticide and other chemical discharges into surface and ground water can not be accurately and consistently measured from any individual farm. This
puts available regulatory instruments into the second-best category right from the beginning, since price and quantity instruments based on environmental damage are unavailable. Other possibilities include taxes or regulation on agricultural output and the use of legal liability. The scope for each of these is severely limited as a management tool, although reduction of output subsidies could have strong positive effects (Able & Shortle 1993). Liability could prove useful in the case of large, unique polluters (like some livestock operations), but will be unworkable in any multiple-polluter case and will carry significant transactions costs in any case.

Griffen & Bromley (1982) demonstrated that with enough information and inter-farm differentiation, the exact same (first-best) results could be achieved by using price (management incentives) or quantity (management practices) instruments on production inputs and methods as by using (infeasible) pollution taxes or quantity instruments. Their message was not that all four were equally good choices, but that measurement problems, uncertainty, policy transactions costs, and other institutional phenomena would dictate the appropriate choice in a given situation. Shortle & Dunn (1986) extended their analysis to argue that given information structure of agricultural regulation, management incentives were more likely to be effective (efficient) because they provide incentives for farmers to make better use of their information advantage over regulators in choosing abatement activities.

The functional difference between management incentives and practices is that the former involve putting a price (either a tax or a subsidy) on marginal levels of that practice with ultimate decisions left to the farmer, while the latter involve mandated limits on input quantities or call for certain levels of particular practices. In theory, management practices and incentives are duals and the same result can be achieved with either. Again, measurement problems, uncertainty, policy transactions costs, and other institutional phenomena would dictate the appropriate choice in a given situation.

Our observation and reading of the literature have led us to believe that problems of monitoring and institutional limitations lead to a relatively clear choice between incentives and practices. Inputs which directly affect the production function and are continuous in nature will be best regulated through incentives; in particular, through taxes. Fertilizers, herbicides, and pesticides are continuous choice variables in agricultural production functions. States have the legal authority to tax these products, and administratively it is not difficult to collect such a tax at the point of wholesale distribution. For example, Iowa has a $0.75 per ton tax on nitrogen fertilizer (CAST 1992). Griffen & Bromley make clear that to be optimal, management incentives must be differentiated by producer. While the taxes themselves are feasible, it is both administratively and politically impossible to differentiate input taxes among differently situated farmers in a given state; taxes will be equal for all farmers.

In contrast, management practices defined over quantities of these inputs are unlikely. As Braden & Segerson (1993) note, the timing and care taken in application have consequences for pollutant loadings independent of the quantity of the input used. Although the EPA can ban a chemical input outright, mandating any particular quantitative limit of fertilizer use or any non-zero maximum level of pesticides or herbicides is difficult to do administratively and almost impossible to observe and enforce in practice.

However, there are a variety of management practices which work by diminishing pollutant loadings from any given level of input application. Forest strips, vegetative buffer zones, and constructed wetlands all filter out or otherwise diminish the pollutant loadings entering surface water produced by any given quantity of inputs. To a reasonable approximation, these practices do not enter directly into the production function except in terms of displacing land from production. The use of incentives in the sense used in the literature does not really apply to these practices. Since they do not enter into the production function, farmers have no reason to engage in these practices unless they are required to do so, or unless they are compensated.

Pilot cost-sharing programs attempted over the past decade have been voluntary and do not fully compensate for the full cost of the management practices. If farmers were taxed a unit amount for not constructing the practice in question, this could be interpreted as an incentive. However, it is functionally equivalent to a regulation with a penalty. Regulatory authority to require this type of intervention is currently quite limited. Farmers who fall under the jurisdiction of the Coastal Zone Management Act can be required to formulate management plans. Authorities also have cost-share funds available to partially compensate the expense of the interventions under pilot programs.

The Conservation Reserve Program also applies to some limited degree. In theory, interventions under this program are continuous; i.e., wider filter strips and buffer zones, larger treatment lagoons and constructed wetlands should provide increasing levels of protection against nutrient and pesticide loading of aquatic environments. In practice, state guidelines for instituting management practices tend to specify a particular level of management practices; for example, a 16 m wide filter strip. Practices will be instituted as part of a formal or informal contract (i.e., a nutrient or chemical management plan) and can therefore be determined on a case-by-case basis.

Different kinds or degrees of interventions, or no interventions, can be negotiated or mandated for different farms, depending on the topographic and soil characteristics of the lands, the nature of farming practices, the health of the watershed, and the number of other pollution sources contributing to any problems. Such individual tailoring requires farm-level participation by regulators, and current manpower resources are inadequate to do this for anything like the entire population of farmers. In addition, legislative and regulatory
authority to date has been unclear or evolving, and farmers can not be absolutely required to construct these solutions. It does seem likely that in the wake of the new Clean Water Act amendments there will be substantially increased authority.

One implication of the difference between the available incentive policies and those instituted as management practices is a reversal of the interfirm efficiency properties of taxes and standards. Management incentives in the form of input taxes lose the automatic least cost property of taxes for two reasons. First, they are taxes on inputs which are imperfectly correlated with the output of pollution. Second, and perhaps more importantly, they will be constrained to be identical across watersheds and across farms with different pollution targets. Standards at least potentially possess the ability to improve efficiency by treating different farms differently, although information and administrative costs and current regulatory institutions make this difficult and expensive. It has been widely recognized how important inter-farm differentiation is for agricultural regulation. An excellent demonstration is given in the work of Taylor et al. (1992), who analyzed a variety of policies for Willamette Valley farms and found that optimal policies were required to be quite different across farm location and type.

It is clear from the regulation of point sources of pollution, however, that passing regulations and achieving them are very different phenomena. Individual farmers and agricultural lobbies have a variety of legal and political means of seeking exemptions, delays, and cheaper solutions. Outright evasion is possible as well (Malik et al. 1993). Reports of farm focus groups indicate that, except in cases where activities are directly profit-enhancing, in the absence of clear regulatory authority the only motivation farmers have for reducing pollution is the hope of avoiding increased future regulation. In any regulatory environment, management practices are more likely to be adopted when the cost to farms is reduced. However, large-scale subsidy programs are unlikely given national budget priorities and traditional attitudes toward the financing of pollution reduction. One possibility is to use the revenue from incentive policies (input taxes) to finance other pollution abatement activities (management practices).

The wide variety of BMPs available for adoption in Georgia highlights the major challenge of this approach. The effectiveness of each practice in reducing nonpoint source pollution depends on crop choice, soil and topography characteristics, and hydrological and loading characteristics of the watershed. Farmers will tend to adopt whichever BMPs are least costly or unfamiliar; there is no guarantee that this choice will be the most cost-effective in reducing pollution to an acceptable level. The research reported here helps to clarify the relationship between individual practices and pollution reduction as a function of timing and crop choice. It is necessary to note, however, that even if the challenge of determining which BMPs should be used can be met, both American and German institutions face a substantial challenge in providing the flexibility and the authority to implement a pattern of BMPs which is both economically efficient and ecologically effective.

5. A Georgia Demonstration Project

The Gum Creek Watershed, located in the U.S. Coastal Plain of Georgia, was identified as a stream likely to be threatened by agricultural nonpoint source pollution and, subsequently, was selected as a water quality demonstration project. This watershed has a gentle relief, warm and humid weather, and fertile soil. Such factors favor intensive agricultural production of diverse crops, including peanuts and corn (maize). Soils with high or intermediate pesticide and nutrient leaching pollution potential cover most of the upland areas of the watershed. Several sub-watersheds have more than 50% of their surface area planted to crops that have high fertilizer and pesticide requirements.

As part of a federal cost-sharing pilot program, the demonstration project sought to reduce potential nonpoint source pollution by inducing farmers to voluntarily adopt BMPs (Georgia Cooperative Extension Service 1992). The restriction of pollution levels, or abatement from current practices, would be compensated partially by government lump-sum subsidies to farmers, assumed to be a sharing of the farmer’s reduction of net returns (opportunity costs) by adopting the new BMP rather than the current management practice. An economic study evaluated the potential for voluntary adoption of BMP alternatives through adoption assessment, biophysical simulation, and mathematical programming under uncertain weather and market conditions (Sun 1994). Farmers’ willingness to cost-share was used to estimate expectations of net returns and associated water and soil pollution based upon government cost-share scenarios. To examine voluntary participation incentives, a watershed survey included willingness-to-accept payment questions in order to enumerate farmers’ adoption probabilities for 4 government cost-share rates – 20%, 40%, 60%, and 80% (with zero and 100% levels implicitly restricted).

Pollution control targets did not exist for comparison with the simulated soil and nitrogen pollution outputs. Thus, soil losses and nitrogen emission levels were restricted to levels less than or equal to the pollution levels corresponding to a management alternative with 122.7 kg/ha of nitrogen and a 50% water availability trigger. Economic modeling assumed maximization of farmers’ expected net returns when agricultural source pollution is restricted under current production technology. Three locally-validated, biophysical simulators were linked to obtain crop yields and pollution output. PEANUTGRO version 1.02 (Boote et al. 1989), a process-oriented peanut crop growth model, was used to simulate peanut crop development, water and nitrogen balance, and peanut yield. CERES-Maize version 2.10 (Ritchie et al. 1992) simulated the growth and yield of a peanuts-corn rota-
tion. GLEAMS (Groundwater Loading Effects on Agricultural Management Systems) version 2.0 (Knisel et al. 1992) simulated the physical movement of agricultural chemicals within and through the plant root zone. The GLEAMS model also generated the chemical pollution and soil erosion output levels, given crop growth parameters, agricultural management systems, and other physical data. Crop yields and nutrient flows to ground and surface water were simulated over 17 years of local weather data and site-specific characteristics of the watershed. Employing corresponding market-year price data, net returns were calculated. Further, the potential pollution effects, combined with the farmers’ probable adoption of cost-sharing, were used to generate annual expectations of net returns and potential emission levels.

Supplemental irrigation was shown to increase farmers’ average expected net returns greatly, while resultant soil losses would remain essentially constant. Nitrogen runoff would increase up to 5%, but nitrogen leaching could increase by as much as 14%. If the resultant effects were less than or equal to watershed area targets set for nonpoint pollution by the EPA, the profitability of supplemental irrigation option is substantial. Nitrogen leaching actually declines slightly at the lower supplemental irrigation rates before increasing at higher, more profitable irrigation rates. Without irrigation, nitrogen leaching could be reduced more than 18% by applying no nitrogen fertilizer. Given the current cropping mix, agricultural sources of potential water quality degradation or enhancement could thus be altered within a limited range of responses.

Over a range of management alternatives, results indicated that irrigation and nitrogen fertilizer applications do not alter water quality in the watershed as much as generally anticipated. Under limited government payments, pollution abatement through reduction of irrigation and/or nitrogen fertilizer applications may significantly reduce farmers’ net revenues and hence, without threats of other regulatory means, more farmers may opt out of a voluntary program. Further abatement of nitrogen leaching should consider other cropping management alternatives or emphasize non-agricultural sources. Optimization results at varying cost-share subsidies showed that nitrogen leaching could be expected to be reduced by up to 10% from baseline results in the scenarios tested. Soil losses and nitrogen runoff were quite inflexible with respect to abatement potential.

6. Baden-Wuerttemberg Study

The conditions for agricultural production in water-protected areas of Germany include proper production techniques and other limitations. Proper production techniques entail the suitable use of the area according to its natural features through practices including varied broad rotations, cover crops, soil conservation practices, nitrogen fertilization according to the nitrogen uptake of the plants, and the use of pesticides under principles of an integrated plant protection plan. Additional limitations required to justify the compensation payments include the reduction of nitrogen fertilization by 20%, the confined use of manure application, cover crops, and use of selected pesticides. For nearly 25% of the fields in the water protected areas, the nitrate amount in the soil was controlled in the fall. If more than 45 kg of nitrate-nitrogen is present in the top 90 cm of soil, it is suspected that the guidelines have been broken. These regulations serve a similar objective as BMPs in the United States.

A research project in Baden-Wuerttemberg evaluated tradeoffs between the use of BMPs to reduce water pollution and farmers’ incomes. An ecological-economic model was used for simulation and optimization of agricultural production strategies for decreasing the erosion and high nitrate content. The CREAMS (Chemicals, Runoff and Erosion from Agricultural Management Systems) (Knisel 1980) soil simulation model was used to determine the ecological impact of management practices to the environment. An economic model was employed to maximize the profit function over two crop rotations: (1) sugar beets–winter wheat–corn–winter wheat; and (2) sugar beets–winter wheat–winter barley. The model was selected to demonstrate how to fertilize each crop over a time horizon of 20 years and how best to split the fertilizer over the growing season. The factors examined were the integrative medium of inputs, turnover, and outputs. Inputs for the model consisted of climatic data, land use, cultural practices, fertilization, and pesticide usage. Outputs of nutrients and pesticides occurred through evapotranspiration, surface runoff, soil erosion, and leaching. Field data consisted of inputs, prices, costs, and sugar beet quotas.

The desired output was nitrogen uptake, as uptake determined yields and avoided excessive nitrogen mineralization in the fall. A governmental premium of 310 DM/ha is lost if mineralized nitrogen exceeds 45 kg/ha in the fall. An optimizing algorithm, COMPLEX (Box 1965), as further developed by Manetsch (1989), was used to maximize the function. The economic model initially chose the nitrogen fertilization level, which was the input variable for CREAMS.

Extensive soil erosion and nitrogen losses may create problems for surface and groundwater in the intensively cultivated loess hillslope countrysides of the Kraichgau. Minimal soil coverage from May until June leads to greater soil erosion. Soil erosion was reduced in the first rotation (sugar beets–winter wheat–corn–winter wheat). The average soil erosion was 30 t/ha/yr with sugar beets, 23 t/ha/yr with corn, and 9 t/ha/yr with winter wheat. In conventional cultivation, soil erosion exceeded the tolerable values. Under conservation systems, soil erosion was reduced through one or more practices, including track loosening in corn (whereby equipment behind tractor tires breaks up and loosens the soil), grass strips in the middle of slopes, or a diversion ditch for runoff water. Therefore, these management practices provided minor protection against excessive soil erosion. A no-till practice or the planting of an intercrop of mustard after
sugar beets or corn were shown to be the most effective system.

Employing a second crop rotation of sugar beets—winter wheat—and winter barley, soil erosion tended to be determined by single events. In years that sugar beets were produced, higher soil erosion occurred. The same rotation with an intercrop of mustard after winter barley reduced soil erosion to about 1 t/ha/yr.

The model showed less nitrogen fertilizer being needed to achieve a maximum income for a producer when compensatory payments for ecological constraints were available. Also, significant amounts of nitrogen remaining in the soil after plantings of winter wheat or winter barley were present. Since the use of an intercrop was able to reduce nitrogen in the autumn significantly, the model used an intercrop of mustard after winter wheat during the first rotation and after winter barley during the second rotation. The analysis also showed that use of a considerable amount of nitrogen fertilizer in spring increased yields and profits without substantial ecological impacts. However, low compensatory payments to reduce nitrogen fertilization levels could provide significant ecological benefits.

7. Summary and Conclusions

BMPs may be implemented by agricultural producers to reduce nonpoint source agricultural pollution, but may not be implemented absent adequate incentive. An interdisciplinary approach is necessary to develop accurate measurements of pollutants, models to identify and monitor negative pollution effects, and consideration of various strategies to maximize net returns to producers within the constraints of targeted water quality standards. As shown in the reported projects from Georgia and Baden-Wuerttemberg, models evaluating institutional constraints of payments to reduce nitrogen usage, penalties for excessive leaching, or financial incentives for meeting minimum mineralized nitrogen levels may identify preferred policies.

A project in Georgia used an economic framework to analyze farmers’ voluntary adoption of water quality management alternatives within a government cost-share project. Supplemental irrigation management appeared to offer opportunities to increase farmers’ expected net revenues with little impact on soil and nitrogen runoff. However, the costs of agricultural pollution abatement by reducing irrigation and/or nitrogen fertilizer application rates were significant. Consideration of other management alternatives, such as restricting the cropland for peanuts in the rotation, may lead to further abatement of nitrogen leaching. As pollution abatement significantly reduced farmers’ net revenues, it is unlikely that producers voluntarily will adopt measures to reduce nitrogen or other chemical pollution.

A project in Baden-Wuerttemberg analyzed soil erosion and fertilization for the development of optimal nitrogen fertilization strategies. Intercropping was shown to substantially reduce soil erosion and nitrate leaching; thus the model showed considerable potential for reducing agricultural pollution. Optimal timing and reduced fertilization would allow increased profits because of compensation payments provided by the government.

Although BMPs can reduce agricultural nonpoint pollution, pollution reduction may be costly to producers. Therefore, reduced pollution probably will require some type of government intervention. One approach is to prescribe BMPs or proscribe practices and activities that create excessive pollution through regulatory institutions. Another approach is to establish pollution thresholds, with penalties for exceeding the threshold or incentives to meet the threshold. While the reduction of agricultural pollution generally remains voluntary in the United States, there has been a willingness to reduce pollution by nitrogen through compensatory payments in the European Union. Further research may disclose more appropriate strategies to reduce pollution while preserving producer incomes.

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