Integrated Assessment of Environmental Effects from Agricultural Production

John G. Lee and Stephen B. Lovejoy

Agriculture's impact on the environment is a complex research problem. A challenge to future economic research is to account for the interrelationship between agricultural production activities, soil productivity, erosion, and water quality. It will become increasingly important to determine not only the economic consequences, but also the environmental effectiveness of alternative policies aimed at improving resource use and quality. The application of biophysical simulation models to environmental quality problems provides a means to better understand the complex interaction between agricultural production and environmental quality.

Mounting public concern for food safety and improved environmental quality related to agricultural production is forcing the agricultural sector to modify its production practices and presents a major challenge to agricultural research institutions. In the past, researchers have focused upon their unique contribution to yield increases (e.g., plant breeding or pest control) or to cost reductions (e.g., farm management or mechanization). However, society's new demands for a cleaner environment coupled with the traditional demands for productivity enhancement will require a multidisciplinary research effort to address effectively these complex issues and the required trade-offs.

For agricultural and resource economists, this will entail working more directly with scientists whose research may be based solely on investigating specific biological and physical processes. These scientists often find it difficult to predict how these processes will interact with real-world situations. Much of the effort in biological and physical agricultural sciences has been focused on the development of simulation models for predicting the consequences of various parameters on plant growth or other processes.

Many of these models have not been calibrated for different geographic conditions or for radical changes in weather, or selected inputs. In addition, these process models often neglect factors important for economic analysis or policy analysis (e.g., changes in management practices implied by the parameter shifts). Hence, many economists may find it difficult to integrate economic or behavioral models efficiently with biophysical or process models. While some economists have used such models in their research, few have attempted to integrate fully the economic and physical attributes into a single simulation model or modelling framework.

A challenge to economists relates to the scale of resource quality assessment where we are often called upon to perform our analysis at the regional or national level, while the physical and biological process models are calibrated for specific attributes. In addition, economists are often requested to evaluate alternative public policies ex ante, while the biological and physical scientists rely on ex post facto results from experimental field plots or monitored watersheds.

Previous economic research on the impacts of agricultural crop production upon the environment has tended to focus on a single resource attribute, while we know that ecosystems are highly interrelated systems where the attributes and niches are linked to each other. Most studies have only evaluated a subset of the vast resource quantity and quality issues. A challenge for further research in this area is to consider the simultaneous impact of crop production practices on multiple factors from the vast array of environmental parameters. A contemporary example would be for our research to consider both soil conservation and water quality impacts of alternative production systems and alternative policies. Agriculture's impact on the environment is a complex process that is difficult, if not impossible, to reduce to a single variable or parameter. While prior research has provided val-

---

John G. Lee is an assistant professor and Stephen B. Lovejoy is an associate professor, both in the Department of Agricultural Economics, Purdue University, West Lafayette, IN. Approved as Journal Paper No. 12743 of the Agricultural Experiment Station, Purdue University.

uable insight to specific resource-allocation questions, a systematic economic analysis is essential to evaluate the relevant trade-offs associated with different agricultural production technologies and policies.

While elaboration of an exhaustive modeling framework is beyond the scope of this paper, we will identify emerging research needs in the area of agricultural impacts on the environmental parameters of soil erosion and water quality. A second objective is to provide discussion on a possible framework to assess crop production impacts on these two integrated resource systems.

Previous Research

Substantial economic research has been conducted in each of the areas of soil erosion, soil conservation, and agriculture's impact upon water quality. This section will review selected studies in each of these areas. While this review is not exhaustive, it does provide a basis to identify areas that merit additional consideration in future research if we are to meet society's demand for a clean environment and farmers' demands for economically feasible production systems.

Productivity Impacts

In the area of soil erosion and conservation, the literature tends to diverge between the topic of maintaining soil productivity and the cost associated with nonpoint source pollution. Several studies have focused on the single resource issue of quantifying the impact of soil erosion on crop productivity and the stream of farm income. The majority of these studies have been conducted at the farm, watershed, or regional level.

Burt used control theory to evaluate the farm-level economics of soil conservation decisions in the Palouse. In this study, Burt defines two state variables to describe the soil resource. The two variables include depth of topsoil and the percent of organic matter in the upper soil profile. Burt indicates that the concern for soil conservation relates to the change in productivity over time at a given site. He concludes that an optimal decision rule approach is very appealing for soil conservation applications because of the slow and smooth rate of change in the state variables over time. However, the particular results derived in the Palouse cannot be easily extrapolated to other areas because of the lack of consistent data in these areas that limit the ability to compare model results over different soils and regions.

By using a dynamic model of soil productivity and erosion-control incentives, Saliba (1985a) suggests that knowledge of the relationship between soil erosion, agricultural activities, and crop yields are vital if we are to understand farm-firm decision making concerning conservation practices. She develops an optimal control model which explicitly considers the interaction between management choices, soil loss, and long-term soil productivity. Unlike prior research efforts, Saliba notes the importance of understanding the relationship between soil characteristics and other crop production inputs which may serve as substitutes or complements. Results from this study suggest that the private incentives to reduce soil erosion depend on the susceptibility of the cropland to erosion as well as the producer's *perception* of the impact of soil erosion on crop productivity.

While some analysts suggest that technological progress will mitigate the negative impacts of erosion upon yields, Taylor and Young suggest that there is an interaction between water-based soil erosion and crop yield. They also indicate that current soil erosion imposes a dual penalty in the future. The first penalty is a direct reduction in future yields as topsoil depth is diminished. The second penalty of current erosion is a reduction in future benefits resulting from technological improvements on eroded soils relative to less-eroded soils. While some future technologies may be helpful regardless of the soil resource's quality, other technologies may only increase productivity for better-quality soils. This suggests that farm firms have greater incentives to conserve soil than just the direct yield reductions.

Miranowski applied a multiple-period linear programming model to evaluate optimal tillage practices and crop rotation selection for firms in an Iowa watershed. He found that under increasing crop price expectations, the market system provides incentives for farmers to adopt production practices that are conservation-oriented. This result is consistent with the recent findings by Pagoulatos, Debertin, and Sjarkowi. Their analysis coupled an erosion-damage function with an intertemporal profit function to determine optimal adoption rates of conservation tillage. They found that low crop prices or high discount rates reduce the rate of adoption of conservation tillage practices.

Weisensel and VanKooten investigated a chemical fallow cropping system relative to a tillage-based wheat-fallow rotation in a dryland region of Saskatchewan. They identified an interesting trade-off associated with soil erosion and soil moisture. They found that conserving soil moisture can be soil depleting, while conserving soil can be moisture depleting. This suggests that some recommended conservation practices do not represent Pareto optimal moves even from the perspective of physical parameters, let alone economic parameters. Although certain soil-conserving crop production systems may exhibit slightly higher net returns compared to conventional systems, widespread adoption of these systems may not occur due to increased variance of returns and producer attitudes towards risk (Lee, Bryant, and Lacewell).

Many of the studies related to quantifying the impact of soil erosion on crop productivity rely on a single measurement of soil movement (e.g., the Universal Soil Loss Equation or U.S.L.E.). Although Burt considered soil depth and organic matter, few studies have done an adequate job of integrating the full range of physical impacts of soil erosion on crop yield. There is more to soil productivity than just topsoil depth and organic matter. Additional research is needed to quantify how changes in soil properties (a multiattribute input) over time influence crop productivity and profitability in a stochastic environment. Following the suggestion of Saliba, it is also important to know the extent to which certain inputs can be economically substituted for inherent soil quality (e.g., to what extent and under what conditions can additional nutrients substitute for topsoil characteristics).

Off-Site Impacts

A second area of research related to soil resources focuses on estimating the off-site costs of soil erosion. An analysis by Moore and McCarl provided an upper-bound estimate of the total cost of sedimentation in the Willamette Valley. They found that two-thirds of the sedimentation in the river, and therefore two-thirds of the social costs, were attributable to soil from agricultural lands. While average annual per acre rates of soil erosion in this area were low relative to other regions in the country, the cost of agricultural sediment on municipal water treatment and maintenance of road drainage systems was substantial.

In an evaluation of soil conservation programs, Ribaudo indicated that off-site damages should also be considered in a targeting program. He suggested that soil conservation programs, which have traditionally been targeted on the basis of on-site productivity criteria, can lead to a very inefficient allocation of resources in terms of off-site impacts such as water quality. While this study raised a number of interesting points, there are several simplifying assumptions that need to be identified and addressed. Ribaudo assumed a single sediment delivery ratio for each of his vast aggregated subareas, even though the topography and precipitation within the subareas are definitely not homogenous.

Distributed parameter hydrologic models such as ANSWERS (Beasley, Huggins, and Monke) show that a single sediment delivery ratio may not accurately predict sedimentation in a given watershed or region. Lee, Lovejoy, and Beasley used a distributed-parameter model to illustrate the diversity of sediment delivery within a small watershed and to suggest the significant gains in efficiency from microtargeting. Ribaudo also assumed that pollutants such as nitrite/nitrates and total phosphorus were carried in direct association with soil particles; however, many agricultural pollutants are water-soluble and are not transported in proportion to total suspended solids. Some research suggests that reducing phosphorus attached to sediment may have little impact upon total phosphorus loadings because the same practices lead to an increase in soluble phosphorus concentrations in the runoff (Lake and Morrison). While these assumptions may simplify the economic analysis, they can lead to a serious bias if one is evaluating alternative water quality/soil conservation programs.

Another area of concern is the preoccupation with the off-site costs of water erosion. While most of the literature on soil erosion and conservation has focused on water-based soil loss, wind erosion accounts for approximately 37 percent of annual total soil erosion (''1982 National Resources Inventory''). The off-site costs of wind erosion have been estimated between $4 billion and $12 billion per year (Piper). In one of the few studies on wind erosion, Huszar attempts to measure the off-site costs of this form of erosion. He found that the off-site costs of wind erosion appear to be a decreasing function of the erosion rate. From a policy perspective, this result implies that low levels of erosion abatement can be less efficient than no controls at all. A similar result for water-based soil erosion control that considers both on-site and off-site damages has been described by Shortle and Miranowski. They conclude that an integrated evaluation of both soil productivity and water quality effects should be considered when one is evaluating different soil conservation programs.

In the area of water quality, previous economic research tends to separate agriculture's impact on surface-water quality from its potential impact on groundwater quality. In an evaluation of four strategies designed to reduce nonpoint source pollution of surface water from agricultural land, Shortle and Dunn found that management-practice incentives to farmers can be more consistent with maximizing expected net social benefits compared to the other options. The other control options included a tax on soil loss, runoff standards, or production standards. In this study, a management-practice incentive represented a tax or subsidy based on a given management practice selected by the producer. In a related study on controlling agricultural sediment, Braden et al. investigated containing sediment rather than reducing discharges. They apply the SEDEC model to simulate erosion, profits, and sediment transport from fields in a watershed in Illinois. Failure to account for transport intervention can overestimate abatement costs and underestimate optimal levels of sediment reduction. They found that targeting the right practices spatially in the watershed can substantially reduce sedimentation compared to uniform tolerance limits.

Relative to groundwater quality, Saliba (1985b) investigated the role of public regulation and private markets for groundwater quality management. Because agriculture is the major user of groundwater for irrigation, mining of groundwater resources can create severe water quality problems (salinity and saltwater intrusion). Contamination of groundwater by agricultural production activities has occurred at several sites around the country. The management of groundwater quality is complicated by the fugitive nature of the resource. Additional factors that complicate groundwater management include the lack of information on the social cost of contamination and the different values placed upon various levels of water quality across multiple users. As Saliba states, quality and quantity are not separable components in an evaluation of alternative groundwater protection schemes.

Separate economic analyses of groundwater and surface-water quality problems is not surprising, given the independent development of various surface and groundwater hydrologic models. For some studies, ignoring agriculture's impact on one water resource and concentrating on the other may be acceptable. However, there are many areas in the country where surface and groundwater systems are integrated (e.g., substantial movement of water from one to the other), and an assessment of policies designed to improve water quality should consider both types of resources.

Most economic research on surface-water quality has focused on sedimentation from agricultural land. An evaluation of agriculture's impact on water quality should consider more than just the cost of sedimentation. These impacts should include the temporal and intertemporal costs of nutrient loading, pesticide fate and movement, salinity, saltwater intrusion, heavy-metal accumulation, and other environmental toxins.

Research Needs

Increasing public concern for improved environmental quality is reflected in a shift in emphasis and funding for agricultural research and education. This shift has manifested itself at the federal level in new programs such as Low Input Sustainable Agriculture (LISA) and USDA/CSRS special grants in water quality as well as USDA's Water Quality Initiative. State initiatives on soil conservation and water quality have also been developed. Additional public concern for environmental safety is reflected in proposed legislation such as Proposition 128, "Big Green," in California and in the environmental provisions of the 1990 Farm Bill.

For many agricultural research institutions, particularly land grant universities, the shift in emphasis to address environmental degradation due to agricultural production presents a significant departure from previous research efforts. Required areas of expertise needed to systematically evaluate environmental degradation caused by crop production may not be available in the current agricultural experiment station. Robust agronomic, economic, and environmental databases needed to assess the economic trade-offs and environmental effects of reduced pesticides and/or fertilization rates do not exist.

The lack of sufficient experimental data coupled with the spatial requirements for assessing soil erosion and water quality impacts present a major dilemma for agricultural and resource economists. This deficiency is particularly critical for ex ante policy analysis. What will be the economic impact on farmers or the agricultural sector from a reduction or ban of a selected pesticide or fertilizer materials? More importantly, what type of environmental improvement will be gained or foregone under such a policy? Will a policy formulated to conserve or improve the quality of one natural resource inadvertently degrade another? What is the cost and value to society of such an improvement? These are difficult questions to address, yet a comprehensive evaluation of alternative policies aimed at improving environmental quality related to agricultural production must take these questions into account.

A second area of concern relates to the spatial or aggregation level of economic/physical analysis. Most of the applications of biophysical models developed to simulate agricultural production processes or environmental effects of production tend to be specific to a particular site with a unique set of physical attributes. In the literature, this is reflected by the large number of case studies. While case studies are useful to define the impacts of a specific policy change or production technology at a given location, it is difficult to draw regional or national policy implications from these studies. As an example, the book entitled *Alternative Agriculture*, published by the National Research Council, contains numerous case-study farms from different regions in the country. While these studies provide interesting examples, it is difficult to derive even an accurate regional assessment regarding the potential impact of alternative production practices on soil and water quality even if our analysis of the economic impact is correct.

From an economic perspective, several case studies assume that input cost, crop prices, and policy parameters are exogenous, while these variables should be endogenous in a regional or national assessment of alternative programs aimed at reducing soil erosion and/or improving water quality. Case studies may provide valuable information concerning potential reductions in soil erosion or sedimentation due to a given agricultural or management practice; however, due to spatial diversity, it is difficult to quantify their aggregate effects on environmental quality.

A third factor, which is not always considered in economic studies of crop production effects on environmental quality, concerns resource dynamics under stochastic conditions. Shortle and Dunn indicate that nonpoint source pollution from agricultural land is inherently stochastic because weather (precipitation and wind) plays a vital role in the physical processes. This implies that soil erosion, sedimentation, and water quality parameters should be expressed as distributions rather than single-value coefficients. Most of the previous farm-level research on soil conservation has not treated soil erosion and sedimentation from different production practices as a random variable. In addition, analyses of alternative policies designed to reduce soil erosion or improve water quality should consider the stochastic nature of these variables when comparing the distributions of program efficiency.

A final note relates to the systematic assessment of agriculture's impact on soil erosion and water quality. In some instances, a management practice or policy designed to enhance the quality of one resource may inadvertently degrade another. For example, several studies have identified the use of crop rotations as being an effective means of reducing soil erosion or sedimentation (Miranowski; Braden et al.; Lee, Bryant, and Lacewell). In portions of the Midwest, the introduction of alfalfa into a crop rotation can significantly reduce annual rates of soil erosion due to water. Preliminary simulation model results in northern Indiana predict a 78% decrease in soil erosion from a corn-alfalfa rotation compared to a corn-soybean rotation (Foltz, Martin, and Lowenberg-DeBoer).

However, adoption of this crop rotation may inadvertently increase nitrate contamination of groundwater resources. The same simulation of a corn-alfalfa rotation predicted a 1,000% increase (4 Kg/Ha^{-1} to 42 Kg/Ha^{-1}) in nitrate loadings to the vadose zone relative to the corn-soybean rotation. While the introduction of legumes may offer the possibility of reducing sedimentation to surface waters, legumes have the potential of increasing nitrate contamination of groundwater supplies. It is this interrelationship between crop production activities and the different types of resource quality that presents a major challenge to economic research aimed at evaluating alternative production practices and environmental policies.

Research Methods

Modelling crop production impacts on environmental quality is a complex process. One means of evaluating these impacts is with the use of biophysical crop growth simulation models. Biophysical simulation models are becoming an increasingly important tool in agricultural research. Application of these types of models can promote multidisciplinary research efforts and improve the economist's understanding of the complex biological and physical relationships. Calibrated biophysical simulation models can also be used to estimate distributions of environmental quality parameters under stochastic weather conditions.

In the area of applied agricultural economics, Mapp and Eidman used a soil moisture–crop yield simulation model to evaluate alternative irrigation strategies. Harris and Mapp used a grain sorghum crop growth simulation model and stochastic dominance analysis to evaluate water-conserving irrigation strategies. Dillon, Mjelde, and McCarl used four biophysical crop growth models to evaluate optimal crop mix in a quadratic programming model of the Blacklands region in Texas. Specific to the assessment of soil erosion, Taylor and Young indicated that simulation models offer more flexibility as compared to programming models in representing the complex interaction through time of soil erosion on crop yields. Musser and Tew provided an assessment of the use and potential of biophysical simulation in the area of production and resource economics. Like many of the tools used in applied research, biophysical simulation models have their limitations. For the type of integrated assessment called for in this paper, a major constraint of present physical/biological process models is that they have been developed for a single purpose. For example, EPIC (Erosion Productivity Impact Calculator) was developed primarily to assess the long-term impacts of soil erosion on crop productivity. The model was not developed to address pesticide or nitrate loadings to groundwater supplies, nor is its framework suitable to address surface-water quality (sedimentation) over areas with diverse topography. Like the problems associated with proper aggregation from the farm unit to the sectoral or aggregate level in economics, evaluation of environmental quality adds an additional spatial aggregation dimension.

A challenge to future economic research and biophysical simulation model development is to formulate models that can account for the interaction between agricultural production, soil productivity, and water quality. While many economic studies have focused on agriculture's impact on a single resource or environmental attribute, the questions posed are increasingly concerned with multiple resources or attributes. In an age of increasing emphasis on discipline-based research, it may be difficult for research institutions to build the structure for development of the necessary broad-spectrum models for environmental assessment. The development of these types of models will require the input and scrutiny from many disciplines, some of which are not represented in traditional agricultural experiment stations (e.g., geography, meteorology, and civil engineering). In addition, development of these models will require increased support and incentives from administrators for the types of research and efforts necessary.

As society continues to place additional pressure on natural resource systems, the demand for environmental quality research will increase. Most of these problems go beyond just agriculture. If land grant universities choose not to broaden their research emphasis to include integrated environmental quality research, other research institutions will adapt or evolve to meet the demand. However, society may not benefit from this move because the new institutions may not have developed the expertise to evaluate sufficiently the crop production or agricultural sector impacts from different policy scenarios.

Conclusions

Agriculture's impact on the environment is a complex research problem. A review of the economic research reveals a myopic evaluation of these integrated-resource systems. A challenge to economic research in the future is to account for the interrelationship between agricultural production activities, soil productivity, erosion, and water quality. A second challenge concerns the scope of regional and national policy analysis related to soil conservation or environmental quality. It will become increasingly important to determine not only the economic consequences, but also the environmental effectiveness of these programs. This type of analysis will most likely require the integration of biophysical simulation techniques and spatial economic models.

The use of biophysical simulation models can provide information and knowledge on the relationship between agricultural production activities, soil erosion, water quality, and crop yield. This type of information is essential for economists working in resource or environmental economics. As Shortle and Dunn state, simulation models can serve as an important tool to diminish the uncertainty about environmental problems.

References

Beasley, D. B., L. F. Huggins, and E. J. Monke. "ANSWERS: A Model for Watershed Planning." *Trans. Amer. Soc. Agr. Eng.* 23(1980):938–44.

Braden, J. B., G. V. Johnson, A. Bouzaher, and D. Miltz. "Optimal Spatial Management of Agricultural Pollutants." *American Journal of Agricultural Economics* 71(1989):404–13.

Burt, R. O. "Farm Level Economics of Soil Conservation in the Palouse Area of the Northwest." *American Journal of Agricultural Economics* 63(1981):83–92.

Dillon, C. R., J. W. Mjelde, and B. A. McCarl. "Biophysical Simulation in Support of Crop Production Decisions: A Case Study in the Blacklands Region of Texas." *Southern Journal of Agricultural Economics* (1989):73–86.

Foltz, J. C., M. A. Martin, and J. Lowenberg-DeBoer. "Low Input Sustainable Agriculture: Economic and Environmental Implications of Increased Alfalfa Production in the Eastern Corn Belt." Selected paper presented at the annual meeting of the American Agricultural Economics Association 4–8 August 1990, Vancouver, BC.

Harris, T. R., and H. P. Mapp. "A Stochastic Dominance Comparison of Water-Conserving Irrigation Strategies." *American Journal of Agricultural Economics* 68(1986):298–305.

Huszar, P. C. "Economics of Reducing Off-Site Costs of Wind Erosion." *Land Economics* 65(1989):333–40.

Lake, J., and J. Morrison, eds. *Environmental Impact of Land Use on Water Quality.* Final report of Phase Two of the Black Creek project, U.S.E.P.A. Project #95-9-81-003. Washington, DC: U.S. Government Printing Office, 1981.

Lee, J. G., K. J. Bryant, and R. D. Lacewell. "Crop Rotation Selection Versus Wind Erosion Susceptibility." *Journal of Soil and Water Conservation* 44(1989):620–24.

Lee, J. G., S. B. Lovejoy, and D. B. Beasley. "Soil Loss Reduction in Finley Creek, Indiana: An Economic Analysis of Alternative Policies.'' *Journal of Soil and Water Conservation* 40(1985):132–35.

Mapp, H. P., and V. R. Eidman. ''A Bioeconomic Simulation Analysis of Regulating Groundwater Irrigation.'' *American Journal of Agricultural Economics* 58(1976):391–402.

Miranowski, J. A. ''Impacts of Productivity Loss on Crop Production and Management in a Dynamic Economic Model.'' *American Journal of Agricultural Economics* 66(1984):61–71.

Moore, W. B., and B. A. McCarl. ''Off-Site Costs of Soil Erosion: A Case Study in the Willamette Valley.'' *Western Journal of Agricultural Economics* 12(1987):42–49.

Musser, W. N., and B. V. Tew. ''Use of Biophysical Simulation in Production Economics.'' *Southern Journal of Agricultural Economics* 16(1984):77–86.

National Research Council. ''Economic Evaluation of Alternative Farming Systems.'' In *Alternative Agriculture*, 195–244. National Academy Press, 1989.

Pagoulatos, A., D. L. Debertin, and F. Sjarkowi. ''Soil Erosion, Intertemporal Profit, and the Soil Conservation Decision.'' *Southern Journal of Agricultural Economics* (1989):55–62.

Piper, S. L. ''Measuring the Particulate Pollution Damage from Wind Erosion in the Western United States.'' *Journal of Soil and Water Conservation* 44(1989):70–75.

Ribaudo, M. O. ''Consideration of Offsite Impacts in Targeting Soil Conservation Programs.'' *Land Economics* 62(1986):402–11.

Saliba, B. C. ''Soil Productivity and Farmers' Erosion Control Incentives—A Dynamic Modeling Approach.'' *Western Journal of Agricultural Economics* 10(1985a):354–64.

———. ''Irrigated Agriculture and Groundwater Quality—A Framework for Policy Development.'' *American Journal of Agricultural Economics* 67(1985b):1231–37.

Shortle, J. S., and J. W. Dunn. ''The Relative Efficiency of Agricultural Source Water Pollution Control Policies.'' *American Journal of Agricultural Economics* 68(1986):668–77.

Shortle, J. S., and J. A. Miranowski. ''Intertemporal Soil Resource Use: Is It Socially Excessive?'' *Journal of Environmental Economics and Management* 14(1987):99–111.

Taylor, D. B., and D. L. Young. ''The Influence of Technological Progress on the Long-Run Farm-Level Economics of Soil Conservation.'' *Western Journal of Agricultural Economics* 10(1985):63–76.

U.S. Department of Agriculture. Soil Conservation Service. ''Data for Decisions: 1982 National Resources Inventory.'' Washington, DC, 1984.

Weisensel, W. P., and G. C. VanKooten. ''Estimation of Soil Erosion Time Paths: The Value of Soil Moisture and Topsoil Depth Information.'' *Western Journal of Agricultural Economics* 15(1990):63–72.

Williams, J. R., K. G. Renard, and P. T. Dyke. ''EPIC: A New Method for Assessing Erosion's Effect on Soil Productivity.'' *Journal of Soil and Water Conservation* 38(1983):381–83.

Wischmeier, W. H., and D. D. Smith. ''Predicting Rainfall Erosion Losses—A Guide to Conservation Planning.'' Agricultural Handbook number 537. U.S. Department of Agriculture. Washington, DC, 1978.