Comparative Economics of Alternative Agricultural Production Systems: A Review

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The agricultural policy agenda in the United States, Canada, and in Western Europe has been increasingly influenced by concerns for the sustainability of agricultural production systems. National, state, and provincial governments in North America are becoming increasingly sensitive to the environmental and human-health risks associated with current modes of agricultural production and policy actions, including restrictions on the use of certain agricultural chemicals and inducements to encourage the use of alternative production practices. Many restrictions and inducements have been undertaken or are currently under consideration in many jurisdictions.

Unfortunately, many policy actions have been animated by high levels of political concern and supported by an inadequate economic database. While it is often recognized that more stringent regulation of production practices and of the use of certain inputs may have an impact on the profitability of farm businesses and on the competitiveness of the regional agricultural sector affected, conflicting views have been expressed as to the nature of those impacts. A rigorous assessment of the comparative profitability of different modes of production is required. This assessment should include an evaluation of comparative income risk as well as expected profit levels since farmers, like others, are risk averse and may be willing to trade expected income for lower levels of uncertainty.

Also of concern in the development of policy is the lack of information about the economic costs of environmental and other types of externalities associated with alternative production systems. While it has been generally recognized that trade-offs exist in the protection of human health and environmental quality, we have an inadequate knowledge about the nature of these trade-offs. For example, it has been well understood that certain compounds used in pest-control products have been detected in groundwater, leading to pressure to reduce the use of those products. If, however, this induces farmers to adopt weed-control systems that more intensely use mechanical tillage, this can contribute to increased erosion and to higher levels of off-site damage as sediment deposition in surface water increases. This too has an environmental and human-health cost. The nature of this and other trade-offs needs to be understood to facilitate the development of appropriate policy.

This paper provides a policy-oriented summary of the contents of the annotated bibliography prepared by Fox et al. (September 1990). This bibliographic survey of the published empirical literature on the comparative performance of alternative production systems for crops and vegetables in North America focused on results published between 1975 and 1989. Studies were grouped into five categories: (1) conservation tillage and soil erosion, (2) pest control, (3) the cost of environmental protection in agriculture, (4) valuation of externalities generated by agricultural production practices, and (5) comparison of organic, alternative, and conventional production systems.

The purpose of this review is to synthesize the published economic research regarding the on-farm profitability and off-farm impacts of agricultural production systems. Efforts have been made to identify areas where substantial agreement is emerging as well as areas where consensus has not yet been achieved. It is our hope that this exercise will both place the development of environmental policy regarding agriculture on a firmer footing and help to identify current and future research needs.

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Conservation Tillage and Soil Erosion

Conservation Tillage

Considerable effort has been devoted to the assessment of both the expected income and the level of income risk associated with the use of soil-conserving tillage practices relative to tillage systems thought to cause higher rates of erosion. Researchers have sought to determine whether erosion control through the use of certain noninversion primary tillage practices represents a net cost or a net benefit to the farm operator in the short run and in the long run. Several analytical techniques have been used. Multiperiod linear programming models have been popular. Simulation models, with and without assessment of risks, have also been used. Enterprise and whole-farm budgets for case-study farms or for hypothetical representative farms have been used in some studies.

The published evidence on the relative profitability and risk of soil-conserving tillage practices is mixed. Berglund and Michalson, using a farm-level linear programming model for the Cow Creek Watershed in Idaho, found that farm income in the watershed would be 8 percent less under a regime of reduced tillage. Johnson and Ali found that while summer fallow, generally thought to underrate topsoil loss, is becoming less economically attractive to wheat farmers in western North Dakota, it does reduce income risk and generates more attractive expected net returns under commodity and input price conditions prevailing in the 1980s. Klemme (1983) compared tillage systems in corn. Minimum-till and conventional tillage produced equal returns to land and management of $179 per acre compared with $168 and $162 per acre of till-plant and no-till, respectively. Later, Klemme (1985) conducted a stochastic dominance comparison of reduced-tillage systems in corn and soybeans. Average expected returns per acre were highest for the conventional-tillage system and lowest for the no-till system. Introducing costs associated with annual soil loss, however, affected the stochastic dominance rankings. Domanico, Madden, and Partenheimer developed a linear programming model of a 294-acre crop and livestock farm in eastern Pennsylvania. The conventional-tillage system was found to be the most profitable, but most erosive system. Mikesell, Williams, and Long evaluated the expected net returns and risk of alternative tillage systems as well as rotations and weed-control regimes for a 640-acre hypothetical grain farm in northeastern Kansas. No-till production systems had slightly higher expected incomes but were more risky. Stochastic dominance analysis indicated that risk-averse farmers would prefer conventional-tillage, continuous-grain-sorghum production. Dickson and Fox compared combinations of tillage systems and rotations for three watersheds in southwestern Ontario. Their findings indicate that conventional tillage (fall moldboard plowing) was more profitable than fall chisel plowing, no-till, or ridge tillage in the long run. Brown, Cruse, and Colvin evaluated production costs and yield for three tillage systems in corn and soybeans. The break-even price for corn was significantly lower under a reduced-tillage system due to reduced production cost; however, the higher yields of the conventional-tillage system gave it a slightly lower break-even price. No-till, due to higher pesticide costs, had the highest production costs. Siemens and Oschwald compared seven tillage systems for producing corn and soybeans in terms of erosion control and crop production. The six conservation-tillage systems greatly reduced soil loss relative to fall plowing. Yields, however, tended to be lower with conservation tillage.

Several studies, however, have concluded that less erosive tillage practices are in fact more profitable than more erosive ones. Doster et al. reported that on lighter soils in Indiana, reduced-tillage (till-plant and fall chisel plow) systems were more profitable than conventional tillage, even in the short run. Hesterman, Pierce, and Rossman found no significant differential in corn yields in Michigan between conventional-tillage and no-till systems. Their results also indicated that the performance of different corn hybrids was unaffected by the choice of tillage system. Keeling, Segarra, and Abernathy report that conservation-tillage systems for cotton in the southern high plains of Texas were more profitable than conventional-tillage systems under a range of associated cultural practices. Williams, Johnson, and Gwin, and Williams (1988) found that conservation tillage in grain sorghum had both higher expected net revenues and lower risk than conventional tillage. Fletcher and Lovejoy found that no-till corn produced net returns of $14–$18 per acre more than conventional tillage, depending on the previous crop. Ridge-till had a higher return by $24 per acre than the no-till plots. Robillard, Walter, and Hexam concluded that a conversion from conventional tillage to reduced tillage increased farm income; however, a conversion to no-till resulted in only a slight increase in farm income. Tew et al. determined that conventional-tillage systems had lower expected net revenues, but also lower variations in net income than reduced-tillage systems. Harman et al. concluded that dryland or irrigated sorghum was more profitable using no-till than conventional tillage.

Perhaps the largest number of published studies, however, report that the relative on-farm performance of soil-conserving tillage practices depends on a number of site-specific factors. The degree to which farmers are risk averse, soil type, topsoil depth, choice of cropping system, level of management, and local climate conditions have all been identified as important variables. Zentner and Lindwall concluded that the use of zero tillage in wheat production in southern Alberta resulted in higher yields through improved moisture conservation. Labor, machinery, and overhead costs were reduced with conservation tillage, but the attractiveness of this production system hinged on the price and efficacy of appropriate herbicides. Pollard, Sharp, and Madison found that chisel plowing was more profitable than moldboard plowing for a sample of Wisconsin farms but that no-till generated a lower net income per acre than the conventional moldboard system. Most of the differences in net revenues were attributed to yield differentials. Fletcher and Featherstone evaluated four tillage systems and found that the effect of choice of tillage system on timeliness of crop production activities and net returns was found to be unimportant under normal weather conditions. Under adverse weather conditions, however, ridge tillage was the preferred system, followed by conventional tillage, chisel plowing, and no-till, respectively. Fletcher and Lovejoy conducted a similar study to investigate the effects of no-till and ridge-till systems on net returns in actual field conditions when compared to conventional-tillage systems. Yields and net returns for the no-till and ridge-till systems were higher than for the conventional system. The extent to which yields were higher was dependent on the previous crop. Harman et al. compared conventional-tillage practices with no-till under an irrigation and fallow system. Relative profits for each system were dependent on the cost of energy required for irrigation. Walker reported that the profitability of conventional tillage relative to conservation tillage depends on topsoil depth. Conventional tillage was more profitable than conservation tillage on deeper soils, while conservation was the preferred system on shallow soils. Taylor and Young similarly concluded for an eastern Washington Palouse area that the shallower the topsoil and the longer the planning horizon, the greater the probability of payoff for conservation tillage.

Pope, Bhide, and Heady emphasized the role of yield differentials across tillage systems as a determinant of net revenues. Four representative farms were studied and net returns to both conservation and conventional systems exhibited substantial variability across farms. Jolly, Edwards, and Erbach compared conventional tillage, strip tillage, slot tillage, and a full-width tillage system for a corn-soybean rotation in Iowa. The full-width system had the highest average returns and the least risk. Conventional tillage had the lowest average returns but exhibited less variability than the strip-till and slot-till systems. Setia's study of the role of risk in conservation tillage in Illinois emphasized that risk-neutral individuals would tend to select a reduced-tillage system, but that under certain circumstances a conventional-tillage system would be preferred by more risk-averse farmers. In a similar study, Setia and Johnson compared various tillage, rotation, and mechanical-practice systems using the Soilec model, and as in the previous study, the level of the farmer's risk aversion impacted the tillage system chosen. Henderson and Stonehouse found that conventional tillage in the form of fall moldboard plowing was more profitable in the long run than spring moldboard plowing, fall chisel plowing, spring heavy off-set discing, and zero tillage on sandy loam and silt-loam soils for corn production in southern Ontario. Zero tillage was preferred on loam soils. Williams, Llewelyn, and Mikesell found that conventional tillage had lower expected returns than no-till in sorghum production in northeastern Kansas, but that conventional tillage had a lower coefficient of variation. Stochastic dominance analysis indicated that risk-averse farmers would select conventional tillage. Similar results were reported for west-central Kansas. Setia and Osborn concluded that the predominant cultural system used in northern Missouri and southern Iowa, a corn-soybean rotation with moldboard plowing and straight rows, was more erosive and less profitable than a continous-corn no-till system with straight rows. Crop production systems that were less erosive than this continous-corn system were less profitable. The marginal cost of reducing erosion beyond the level predicted with no-till continuous-corn ranged from \$2.38/ton/yr to \$7.04/ton/yr across soil groups. Finally, Hinman et al. made a cost comparison of no-till, conventional, and conservation barley tillage systems. Conservation tillage and no-till had lower associated tillage costs, although the increased cost of chemicals for no-till partially or wholly offset this decrease in machine costs. Pagoulatos, Debertin, and Sjarkowi determined that the optimal timing of conversion from conventional tillage to no-till was dependent on output price, topsoil depth, discount rates, the capital cost of conversion, and the difference between yield and net cost of alternative production systems.

The Costs and Benefits of Controlling Soil Erosion

This section summarizes those studies that have estimated the costs and benefits of controlling soil erosion through the adoption of production systems, specific cultural practices such as rotations, contouring, or terracing, or policy in the form of soil-loss restrictions or taxes and incentives. Linear programming and simulation models were the most frequently used techniques.

Barbarika and Dicks estimated the annualized treatment cost per acre of reducing erosion to a tolerance level on highly erodible cropland in the U.S. Costs, estimated as a function of erodibility of land, level of treatment, type of erosion, and regional location, were as high as $667 million per year or $15 per acre. The impact of production systems and specific cultural practices on soil erosion rates and on farm incomes has been examined by various authors. Rosenberg, Knutson, and Harmon concluded that the cost of erosion control for farmers in the southern Iowa River basin exceeded the benefits. Use of cultural practices that would reduce the rate of topsoil loss was estimated to cause a reduction in regional farm income in the range of $49 million to $97 million per year (1974 constant dollars). Simulation analysis was used by Setia and Osborn to compare net returns per acre and the estimated rate of soil loss for eight rotations, three tillage systems, and three cultural practices. Results indicated that the soil-conserving practices were less profitable than conventional practices and also that the marginal cost of reduced soil loss across soil groups ranged from $2.38/ton to $7.04/ton. Bills compared the productivity of erosive New York farmland to that of less erosive land using the Universal Soil Loss Equation. The comparisons suggested that highly erosive cropland performed like much less erosive cropland when used with a high level of management. Narayanan concluded that the conventional crop production system used in the black soil zone of Alberta generated higher farm income than a conservation-oriented system. The difference was attributed to higher variable costs with the conservation system Segarra and Taylor analyzed the impact of up-and-down-the-slope cultivation, contouring, strip cropping, and terracing on soil loss and net present value of returns. These farming practices were analyzed under three technological-change scenarios. With no technological change, contouring yielded the highest optimal net present value followed by up-and-down-the-slope cultivation, terracing, and strip cropping. Terracing had the lowest rate of gross topsoil loss. Results indicated that rates of technological change had little impact on the relative ranking of the four farming practices in terms of net present value of returns and soil losses. Christensen and Heady estimated that if soil-conserving practices were used to produce additional grain corn for twelve billion gallons of alcohol for fuel, soil loss would not increase substantially.

The impacts of soil-loss restrictions and other soil erosion control policies on producers and consumers were also examined in the literature. A linear programming model was used by Forster and Beckar to estimate the impact of restrictions and taxes on soil loss and a subsidy for the reduction in soil loss on farm income of a watershed in northern Ohio. Restrictions generated modest declines in farm incomes. A tax/subsidy of $6 per ton led to a net increase in the total of net farm income plus the net effect on the public treasury. Higher subsidies led to a reduction in this total. A modest reduction in soil losses was predicted. Seitz et al. utilized a static linear programming model to assess the impacts of soil erosion control policies in the Corn Belt at regional and watershed levels of aggregation. A soil-loss tax of $2/ton, a soil-loss restriction of 3 tons per acre, and a 3-ton-per-acre soil-loss restriction combined with a 50 percent subsidy for the cost of terracing were evaluated. The $2/ton tax had the lowest social cost of $192 million and reduced soil loss by 337 million tons. The 3-ton-per-acre soil-loss restriction produced nearly the same soil-loss restriction but had a social cost of $480 million. Under the cost-sharing policy, total soil loss was reduced by 360 million tons but had net social costs of $495 million. Significant variation in economic impact among regions was reported, mainly as a result of the difference in physical characteristics of farms across regions. Nelson and Seitz used an intertemporal linear programming model to study the effects of topsoil loss and nitrogen-use restrictions on farm income and topsoil loss. It was found that topography was an important factor in the variability of effects and that actions to control topsoil loss and to reduce nitrogen use generally led to lower farm incomes. Zinser et al. evaluated soil-loss restrictions of 10-, 5-, and 3-ton limits on average per acre soil erosion and sediment-abatement subsidy policies of $1, $6, and $10 per ton per acre and concluded that both policies resulted in a decrease in net farm incomes and also concluded that an increase in energy prices reinforced the effectiveness of these policies.

Summary

Five generalizations can be made from the studies reviewed above.

1. On-farm performance of soil-conserving tillage systems varies with location, soil type, climate, level of management, and crop produced.

2. While some examples of soil-conserving tillage systems that are more profitable than commonly used conventional tillage have been found, further gains of reduced erosion can generally only be obtained at the expense of farm income. At least beyond some point, the marginal cost of soil conservation is a positive and increasing function of the amount of topsoil conserved.

3. In addition to average or expected net revenue, the riskiness of net revenues matters. In many situations, conservation tillage has been found to be a production system that is more profitable, on average, but also more uncertain.

4. The emphasis on the long-run productivity effects of erosion has failed to acknowledge the very real incentives to control on-site damage that farmers face. To the extent to which productivity losses in the future depress future income, the current wealth of a farmer (measured in present-value terms) falls. Self-interest on the part of the landowner dictates that actions will be taken to protect current wealth if the benefit of those actions exceeds the cost. A growing empirical literature has documented that there is an inverse relationship between land prices and erosion rates as well as cumulative erosion (see Fox and Taff).

5. Conservation tillage, in isolation, is probably not the answer to higher levels of soil conservation without income loss. Modifications to existing cultural practices, including rotations, pest-control systems, and crop choice, along with the evolving technology of conservation tillage, show more promise.

To determine the profitability of specific tillage systems, it is necessary to determine the impact of factors such as soil type, climate, and crop produced, and the interactions of these factors on the productivity and soil erosion levels associated with the particular tillage system. To date, the literature has not adequately quantified these relationships, and as a result, the profitability of conservation-tillage systems in the current literature is inconclusive. As previously mentioned, conservation tillage, in isolation, is probably not the answer to higher levels of soil conservation without income loss. In order to determine optimum combinations of tillage system, rotation system, pest-control system, and policy, it is again necessary that an understanding of the interactions of such systems be known. The uncertainty of the profitability of conservation tillage also has not been adequately addressed in the literature. The effect of this uncertainty on the farmers' decisions to adopt a conservation-tillage system requires further study.

The role of long-run productivity effects as an incentive for farmers to adopt conservation tillage has been inadequately treated in the soil conservation literature. Future productivity losses due to soil erosion and the impacts of these losses on future income and current wealth must be established in order to determine the extent to which long-run productivity effects provide incentives for the farmer to adopt conservation-tillage systems.

Pest Control

Alternative Pest-Control Methods

The effect on yields and returns of a variety of agricultural pest controls have been evaluated in the literature. The pests studied range from insects in apples to weeds in field crops. Control measures considered encompass a host of alternatives. Regardless of the type of pest, the control strategies evaluated for comparison can be generally classified into an intensive pesticide-application system, a moderate or flexible system, and a biological or cultural control system.

Partial budgeting is the most common analytical technique used in these studies. The raw data are generally collected through field trials, although some studies have used biological simulation models to characterize the dynamics of the pest population. Other studies have used mathematical programming techniques to determine an optimal strategy. Linear programming is often employed, although recent studies have used dynamic programming, which more readily incorporates the intertemporal and stochastic nature of the pest-control problem.

A small number of studies have documented the benefits of intensive herbicide applications. Nastasi, Frans, and McClelland evaluated eighteen different weed management systems to control grass in cotton and found total weed control costs without the use of herbicides, which included cultivation and hoe labour, were significantly higher than on plots where single or combined applications of herbicides were used. Highest net returns were obtained for over-the-top herbicides followed by preemergence applications.

The result found by the majority of the studies was that the most profitable pest-control strategies were generally flexible management strategies that involved a combination of control measures. Miranowski evaluated three pest management strategies for corn rootworm: soil insecticides, pest monitoring with insecticides used only when needed, and cultural control (no insecticides). The cultural-control system was found to yield the lowest returns per acre under alternative price scenarios. Monitoring was found to be more profitable relative to the other strategies at higher energy prices as information services were substituted for insecticide inputs. White and Thompson reported savings of $26 per acre for producers in a tree-fruit integrated pest management program in New York. However, Rossi, Dhillon, and Hoffman found integrated pest management strategies for apple producers in New Jersey resulted in only small net savings in cost with no significant difference in yields when compared to conventional pest management practices. An econometric simulation model of production and consumption of major U.S. agricultural crops was used by Taylor et al. (1983) to measure the impacts of alternative regional boll weevil eradication and management strategies. Eradication, combined with integrated pest management strategies, had the highest social benefit, but also the highest public costs. The optimal program depended on government budget priorities. A stochastic dynamic programming model was used by Zacharias and Grube to determine optimal integrated management strategies for simultaneous control of corn rootworm and soybean cyst nematode in Illinois. The best soil-insecticide application strategy and crop rotation depended on product prices and the infestation levels of the pests. Liapis and Moffitt analyzed four alternative strategies for controlling cotton bollworm. Results indicated that biological control of cotton bollworm was preferred to other integrated pest management strategies when risk aversion was an important characteristic of producer behavior. The yield and producer returns of short-season cotton production systems were examined by Masud et al. under integrated pest management and typical pest management strategies. Producer returns were the highest for the short-season cotton varieties grown under integrated pest management. The expected income and risk impacts of conventional pest management and three integrated pest management strategies were evaluated by Greene et al. for a soybean-growing area in Virginia. The three integrated pest management strategies generated a greater expected income than conventional systems and were ranked highest by risk-averse farmers. Musser, Tew, and Epperson analyzed expected returns and income risk using data from alternate integrated pest management experiments conducted at the University of Georgia. Four pest management levels were analyzed. The management level that included the application of a herbicide, foliar fungicide, and use of an insecticide on the basis of scouting reports had the highest income and was preferred by producers, regardless of risk preference.

Beattie used field-plot data to calculate gross margins on Ontario soybeans under different weed-control methods and found that a combination of herbicides and cultivation produced significantly higher returns than both cultivation alone and herbicides alone. Lybecker et al. compared a standard and herbicide-intensive weed management system over a six-year period for two crop rotations in Colorado. Returns were generally higher for the standard weed management system, but higher output prices and a continuous-corn rotation favored the herbicide-intensive system. Monks found that cultivation used in conjunction with herbicide applications to control weeds in narrow-row snap beans produced net returns significantly higher than for plots treated with herbicides and not cultivated. A bioeconomic model was developed by King et al. to evaluate four weed management strategies for continuous corn in Colorado. The lowest annualized net returns were generally for the system using pre-emergent herbicides, while the highest returns were found for the most flexible strategy, which could use both pre- and postemergent herbicides, depending upon conditions.

Bridges and Walker evaluated the economic effects of sicklepod control in Alabama. They found intensive input systems consistently resulted in higher levels of weed control regardless of the tillage practice or tillage system. However, the resulting higher yields did not necessarily translate into increased profits, given the increased costs of herbicide applications. The highest net returns were generated through controlled densities of sicklepod. Wilcut, Wehtje, and Walker found that for peanut production in Alabama, the traditional weed-control system of cultivation and soil-applied herbicides generated higher expected returns with less variability than a system that employed postemergence herbicides. They found that returns to weed control in peanuts were highest for a combination of herbicide and mechanical cultivation in comparison to each system individually. Lybecker, Schweizer, and King analyzed four weed management systems ranging from moderate to intensive use of herbicides over the different crops of a barley/corn/pinto bean/sugar beet rotation in Colorado. The system using the least amount of herbicide had the highest return, but the results were sensitive to input and output prices. The herbicide-intensive system was the least risk-efficient. Snipes et al. used analysis of variance to test for differences among combinations of cultivation, hand hoeing, and/or herbicide application in controlling weeds in cotton. Negative returns consistently occurred with cultivation alone, although the addition of hand hoeing did improve yields slightly. The results revealed that herbicide application without cultivation was the most economical; however, it was the opinion of the authors that herbicides plus cultivation was the most reliable treatment and therefore the most economical long-run system of weed control. Baldwin, Oliver, and Tripp surveyed soybean farmers in Arkansas on their response to university recommendations on herbicide application rates that were as low as one-fourth of label guidelines. Savings to producers averaged approximately $7.70 per acre, but concerns were raised about the lack of management skills to use the lower herbicide levels on large acreages. Reichelderfer and Bender conducted a benefit-cost analysis of chemical, biological, and integrated pest management controls of Mexican beetle in soybeans. Biological control yielded the highest return per dollar spent on pest control at the producer level and was found to have the highest social returns to expenditure.

Costs and Benefits of Pesticides

Numerous studies have been conducted to determine regional and national costs and benefits associated with the use of pesticides. Linear programming, economic-surplus models, partial budgeting, and maximization models have been used. It has generally been found that pesticide use represents a net-income benefit to farmers.

Stemeroff et al. evaluated herbicide treatments on Ontario corn and soybeans and found all treatments resulted in positive yield effects and net benefits to producers over control plots. The average benefit-cost ratio for all types of herbicide treatments was 2.61:1 for soybeans and 2.80:1 for corn. Fox (1990) estimated that quackgrass infestations in major field crops in eastern Canada reduced total farm revenue by $42 million.

Considerable effort has been devoted to the study of the impacts of restrictions on the use of pesticides on net farm income. Cashman, Martin, and McCarl (1981) considered the effects of bans of various herbicides on the net incomes of Indiana corn and soybean farms. Bans of individual herbicides were predicted to reduce yields and to lead to a fall in incomes of 32% to 38%. A ban of all dinitroaniline, triazine, and amide herbicides was projected to reduce net farm income by 65%. Burton and Martin determined that restrictions on the use of single herbicides would not have a major effect on production levels or prices, as the banned product would simply be replaced with its most effective substitute. When all herbicides used in corn and soybean production were banned, however, corn, wheat, and soybean prices rose by 13% to 16% as output levels fell. Taylor, Lacewell, and Talpaz examined the effect of a total withdrawal of pesticides used in cotton production. A decrease in producers' and consumers' surplus of $774.6 million would occur as a result of a total pesticide withdrawal. The impacts of restricting Ridomil on tobacco prices, costs, producer revenues, and consumer expenditures were estimated by Norton and Bernat. Results indicated that if Ridomil were unavailable, net revenues would decline by as much as 26% for flue-cured production and 8% for burley production.

Studies of the effects of pesticide bans in Canada have produced broadly similar results. Dunnett concluded that the loss of Captan would lead to annual losses of $100 million to $150 million per year to the Canadian economy. Krystenak estimated that the value of additional grain made possible from use of 2,4-D was $176 million in 1979. If less effective herbicides were used in place of 2,4-D, farm costs would rise by $66 million. Fox suggested that the ban of Alachlor in Canada could lead to a 15% to 35% increase in the price of other grass herbicides, which would reduce producers' surplus by $2.6 to $6.2 million per year if Alachlor use continued in the U.S. If the U.S. were to ban Alachlor, grain prices could rise and actually make Ontario grain corn and soybean producers better off.

Summary

Five general conclusions can be drawn from the studies reviewed regarding pest-control strategies.

1. The use of pesticides provides a net benefit in terms of farm income.
2. A flexible control system that involves a combination of possible control measures, where the control measure to be chosen depends on factors such as crop price or pest infestation, generally produced the highest net returns.
3. Complete control of the pest is not generally economically efficient, but the optimal level of eradication increases with output prices.
4. Although complete biological control is favored in only one circumstance, the incorporation of these methods into a flexible pest management strategy becomes more attractive when the analysis includes the broader social effects of the alternative strategies.
5. The cost associated with restrictions of pesticides varies with the nature of the pest-control

problem, the availability of substitute strategies, and the regional scope of the restriction.

Information is required on the development of economic thresholds for pesticides. Considerable research has been conducted to determine economic thresholds (Getz and Gutierrez; Mumford and Norton; and Pedigo, Hutchins, and Higley). However, much of this work has been conducted using a static model with the assumption that pesticides offer the only form of pest control. Further research is required to determine the economic thresholds for pesticides under flexible control systems. The many factors that have been identified by the summary to affect the degree of the cost and benefit of pesticides, such as prices, multiperiod effects, and weather, must be incorporated into the calibration of economic thresholds.

The Cost of Environmental Protection in Agriculture

Estimates of the value of externalities generated by agricultural production practices are rare. However, many studies have calculated the costs to farmers, consumers, and taxpayers of actions taken to reduce those externalities. Studies in this section primarily address the cost of policies intended to reduce contamination of groundwater by applied fertilizer, pesticides, and manure. In addition, studies estimating the cost of reducing sediment disposition in surface water are also reviewed. Policies examined include restrictions on applications, taxation, and restrictions on per acre soil losses. The impacts of these policies on net farm income, food prices, production costs, and producers' and consumers' surpluses have been reported. The majority of studies in this section have utilized linear programming models to estimate costs. Interregional, multiperiod, static, dynamic, and aggregate effects have been incorporated into a number of studies.

Several studies have evaluated the cost of addressing the problem of nitrogen and phosphorus contamination of surface water and groundwater. Palamini estimated the impact of nonpoint nitrogen control on agriculture for two counties in Illinois. Restrictions on nitrogen use reduced nitrogen purchases, whereas tax policies were found to have no effect. Casler and Jacobs, using a linear programming model, determined that the cost to farmers of reducing phosphorus deposition in Cayuga Lake in New York through changing from corn to hay was 10% of net farm income. Heady, Nagadevara, and Nicol concluded that actions to protect soil or water quality would be difficult to implement unilaterally in Iowa since action taken to reduce rates of topsoil loss or to limit nitrogen applications caused aggregate net farm income to fall in Iowa and to rise in the rest of the U.S. In a similar study Heady and Vocke used an interregional programming model to evaluate the impacts of control policies on soil erosion and nitrogen runoff nationally. Under all the alternatives analyzed, U.S. agriculture could still meet domestic food needs with a 7.4% increase in food prices. Rathwell, Badger, and Tucker used an aggregate linear programming model to study the effect of restricting nitrogen use on the amount of land needed to produce current quantities of wheat, grain-sorghum, and corn in the Texas-Oklahoma Panhandle. An additional 696,000 acres would be needed in 1975 and 178,000 acres would be required in 1990 to produce the output obtained from this region in 1972. Horner used a multiperiod programming model to compare the income effects of imposing an effluent charge on pollution-emitters or the use of a treatment plant to achieve specified nitrogen pollution standards in subsurface irrigation return flows in the San Joaquin Valley of California. Total annual income in 1970 dollars was $40,626,000 if no restrictions were placed on drainage-water disposal. Using the effluent charge reduced total annual income to $40,101,000, while the use of a treatment plant reduced total annual income to $39,267,000. Jacobs and Casler compared the impact of reducing phosphorus discharge from crop production in central New York using effluent taxes versus uniform reduction. For a 20% reduction in phosphorus discharge, social costs in the watershed were $126,556 for effluent taxes compared to $132,748 for the uniform reduction policy. Pfeiffer and Whittlesey evaluated the efficiency and the impacts on agriculture in an eastern Washington river basin of alternative water quality improvement policies. Policy alternatives ranged from a nitrogen-fertilizer tax, a per acre foot charge for irrigated water, and a general reduction in water rights. Net social costs ranged from a minimum of $9.7 million under a combined nitrogen-fertilizer tax and an irrigation water charge to $16.6 million for a uniform reduction of water rights. The policy with the highest social cost had the least net producer cost of $16.6 million.

Other studies considered contamination by pesticides or sediment. Taylor and Frohberg, and Taylor, Frohberg, and Seitz studied the effects of erosion controls, herbicide bans, and limits on fertilizer applications in the U.S. Corn Belt. The commodity price effects of a herbicide ban were estimated to reduce consumers' welfare by $3.5 billion per year. Producers' surplus was projected to increase by $1.8 billion per year as a result of higher grain prices. An insecticide ban was estimated to cost consumers $632 million per year while increasing producers' surplus by $531 million. Restricting nitrogen use with a 100 lb/acre limit reduced consumers' surplus by $231 million. A more stringent limit of 30 lb/acre decreased consumers' surplus by $3.3 billion. Producers were made better off by $21 million and $2.0 billion with 100 lb/acre and 30 lb/acre limits, respectively. Baker analyzed the trade-off between groundwater contamination and a viable farm economy for a potato farm using a recursive stochastic programming model. Subsidies for low-input crops offered farmers the highest return of any policy, but at a cost to local government. A ban on pesticides caused a decrease in farm income, but the reduction was small in comparison to the improvement in environmental quality. Dinan and Salassi examined the impact of two potential Environmental Protection Agency (EPA) policy scenarios using the REPFARM model. The first policy assumed past and current EPA actions plus a conservative set of assumptions about future actions, while the second scenario assumed past and current actions plus an expensive set of assumptions about future actions. Net cash farm income declined by $270 and rose by $4,800, respectively, for the average Illinois corn and soybean farm, and declined by $1,700 and $1,300, respectively, for the average cotton-soybean farm in Mississippi. Spurlock and Clifton investigated the equity and efficiency impacts of two alternative sediment-control policies for a river basin in Georgia. One policy restricted sediment delivery in each of the seven resource groups in the basin to an average of one-half ton per acre. The second policy constrained sediment delivery in the whole basin to an average of one-half ton per acre. Both policies reduced net returns per acre relative to the situation in the absence of policy. The second policy cost $1.5 million less than the first to achieve the same level of sediment control. Shortle demonstrated that the uncertainty on flows of water pollutants from agricultural sources from hydrological models was not neutral with respect to the optimal level and allocation of estimated abatement or with respect to the expected net benefits of alternative pollution-control policy instruments. Shortle and Miranowski (1983) suggest that the use of a dynamic model for erosion-control decision making that incorporates the intertemporal interdependence between cost and returns to agriculture at different points in time may benefit future research.

The cost of reducing water contamination from manure and manure runoff has also been addressed in the literature. Heimlich analyzed the economic and environmental effects of different manure-handling systems for northeastern U.S. dairy farms. Reductions in phosphorus loading through the use of increased manure storage capacity was significant; however, investment in manure systems could not be justified by either nutrient conservation or labor savings. Southgate et al. similarly concluded that an annual subsidy of $7,000 per farm would be required for northern Wisconsin farmers to adopt less-polluting manure-handling systems. McSweeny and Shortle examined the impact of policies to reduce nitrogen losses on a mixed crop-livestock farm under various types of production risk. The policies included restricting nitrogen application, restricting animal densities, information and education programs, and taxing either commercial fertilizer or total nitrogen application. Application rates and policy responses were sensitive to the risk preferences of farm operators. Mandated reductions in application cost less and accomplished more than limiting animal densities.

Summary

The inelastic nature of demand for many agricultural commodities means that input-use restrictions that reduce output can lead to higher farm prices and can increase farm incomes. Consumers' welfare, however, falls. Regional effects are also important since the demand elasticity faced by a single region depends on the supply elasticities of other regions as well as the elasticity of total demand. In export markets, Canada faces relatively elastic demand conditions, and variations in Canadian production have little effect on prices. As a result, unilateral bans of certain inputs and cultural practices can reduce farm income.

Valuation of Externalities Generated by Agricultural Production Systems

While concern about the externalities associated with agricultural production practices is high, the knowledge base about the economic value of those externalities is seriously limited in scope. Most of the available estimates of external costs relate to the off-site damages caused by eroded sediment. These estimates indicate that the off-farm damages of sediment impose substantial costs downstream and that these costs dwarf the estimates of on-farm damages from erosion. Once it leaves the farm, eroded topsoil has been linked to the degradation of fish habitat and spawning areas, to reduction in the value of recreational and commercial fishing, to increased maintenance and dredging costs for navigation channels, drainage and irrigation infrastructure, and reservoirs, to deteriorations in quality of beaches, and to increased water-treatment costs. Clark, Havercamp, and Chapman estimated that erosion from U.S. cropland causes $2.2 billion (1980 dollars) in off-site damage annually in the U.S. Ribaudo (1983), using the approach of Clark et al., estimated that for ten major categories of off-farm damages, the total annual off-farm cost of erosion was $7.0 billion (1983 dollars). Holmes estimated the national cost of treating degraded surface water resulting from agricultural runoff. The nationwide treatment costs to water-treatment firms were estimated to fall between $458.34 million and $1.37 billion per year. Ribaudo (1988) concluded that the use of buffer strips to reduce the rate of sediment deposition in streams adjacent to cropland would generate $67.70 of off-site benefits per acre of cropland. Moore and McCarl confirm the large magnitude of off-site damage from cropland erosion in Oregon. A gross benefit of $3.5 million annually (U.S. 1988) for water quality improvement was estimated for two lakes in South Dakota by Piper, Ribaudo, and Lundeen. Dickson and Fox (found under "General" in the references) concluded that the off-site benefits from the use of conservation tillage on cropland in southwestern Ontario range from $9.55 to $69.23 per hectare per year in selected watersheds. These estimates are large compared to reported values of on-site damage. Given the questionable economic relevance of the available estimates of on-farm damage from erosion (van Vuuren and Fox; Fox and Taff), the overwhelming emphasis on on-site effects in the design of soil conservation policy seems misdirected.

Relatively few studies have estimated the value of other types of externalities from agricultural production practices. Our survey has located only one. Siebert reported that unintended kills of honey bees from insecticide use cost California honey producers about 4% of their annual income in 1975 and reduced the income of almond growers by about 0.3%.

Summary

Traditionally, soil conservation policy has been animated by concern for the future of productivity of farmland. Much attention has been focused on the so-called costs of erosion to farmers. Soil conservation as an environmental protection issue has not been emphasized. The economic literature suggests that a reorientation of priorities is in order. Soil erosion is a serious environmental problem in North America. Treating it as such prompts consideration of policy instruments employed in other environmental protection problems. This set of control instruments includes the use of taxes and subsidies, standards and regulations, strengthening property rights, and other policies familiar to analysts of environmental policy. Also, targeting criteria for soil conservation efforts intended to address an environmental protection agenda would likely differ from criteria developed out of concern for long-run productivity effects. In general, no reliable correlation exists between the severity of the on-site effects of erosion and the economic costs of the externalities generated by soil loss. As a consequence, policies directed at reducing the on-farm effects of erosion are unlikely to be effective instruments in the reduction of off-farm effects. Many studies have found that conservation tillage is an economically attractive control strategy for reducing sediment damages. It should be emphasized, however, that more attractive control strategies may be available. Streambank rehabilitation, buffer strips, and the use of grass waterways may be capable of generating benefits comparable to the gains from widespread adoption of conservation tillage at a lower opportunity cost.

If the volume of published literature is any indication, study of the on-site productivity effects of erosion and the mitigation of those effects through conservation tillage has dominated the research agenda on the economics of soil erosion. We know very little about the value of economic externalities generated by alternative crop production systems in different regions. This is true not only for the off-farm effects of sediment displaced by cultivation, but also for the off-farm effects of herbicides and nutrients deposited in surface water and leached into groundwater. This lack of information has serious consequences. While it is generally recognized that trade-offs exist in the protection of human health and environmental quality, we have inadequate knowledge about the nature of those trade-offs. For example, it is well understood that certain compounds used in pest-control products have been detected in groundwater, leading to pressure to reduce the use of those products. If, however, this induces farmers to adopt weed-control systems that more intensely use tillage, it is also well understood that this can contribute to increased erosion and to higher levels of off-site damage as sediment deposition in surface water increases. This too has an environmental and human-health cost. The nature of this and other trade-offs needs to be better understood to facilitate the development of effective policy. It seems reasonable to presume, however, that alternative production systems have differential effects on groundwater quality, surface-water quality, wildlife habitat, and long-term soil productivity. Development of appropriate means of protecting soil, water, and other resources from adverse effects of food production requires a recognition of the multiple dimensions of the effects of alternative production systems and empirical investigation of the nature of the trade-offs involved.

Comparisons of Organic, Alternative, and Conventional Production Systems

Several studies, in recognition of interactions of components within a crop production system, have sought to use a systems approach to compare the performance of alternative modes of production. Below we compare the results of studies evaluating organic production systems against conventional production systems. An organic production system is defined here as any system that does not use synthetic pesticides or fertilizers purchased from sources off the farm. This is followed by a summary of studies in which alternative crop rotations and tillage systems were compared against summer fallow and conventional systems. The various production systems examined in these two sections have been compared in terms of cost, yield, net farm income, income variability, and price effects. Enterprise and whole-farm budgets have been the most frequently used analytical procedure, but multiperiod linear programming models have also been used.

Organic vs. Conventional Systems

The relative profitability of organic versus conventional production systems has been compared in numerous studies. However, neither system has consistently outperformed the other. Klepper et al. and Lockeretz et al. compared the financial performance of fourteen matched pairs of organic and conventional farms in the U.S. Corn Belt for 1974 and 1975. Farms in the study produced both crops and livestock, and organic farms in the sample had been managed without inorganic nitrogen fertilizer, activated phosphates, potassium fertilizer, or pesticides for six years prior to 1974. Yields were higher on the conventional farms in 1974 and 1975, but average returns per acre were roughly the same on conventional and organic farms. Procedures used to select farms to be included in the study make it difficult to draw general conclusions from the study. Shearer et al. followed up on this early work with a further performance comparison for a different sample of farms in the Corn Belt for 1977 and 1978. In 1977, which was judged to be a poor crop year, returns on organic farms, expressed on a whole-farm and on a per hectare basis, were comparable to conventional farms. In a better crop year, 1978, whole-farm income was higher on conventional farms. Berardi compared organic versus conventional farming methods in terms of economic costs, energy inputs, and yield for wheat. The average profitability for conventional farming was $59.50 per hectare compared to an average of $14.55 per hectare for the organic methods. Conventional farming methods produced 29% higher yields than organic methods.

Dobbs, Leedy, and Smolik compared conventional, ridge-till, and an alternative production system for grain farms in South Dakota by conducting two field studies. No synthetic fertilizers or herbicides were used in the alternative system. In one study, ridge tillage was the most profitable, followed by a conventional system. The conventional system generated almost twice the net farm income of the alternative system. In the second study, incomes of all the systems were substantially lower and differentials among the systems were smaller. The alternative system had the highest net farm income in this project.

Goldstein and Young compared conventional and low-input systems for grain and legume production in the Palouse region of the northwestern U.S. for 1986 yield price and cost conditions. The low-input system used no synthetic fertilizer and no pesticides on medic or winter wheat. Recommended rates of pesticides were applied to peas. The low-input system was more profitable than the conventional system when crops were valued at current market prices, but when target prices were used, the conventional system was more profitable. Medic was used in rotation in the low-input system to fix nitrogen for the wheat crop to follow. Mends, Dobbs, and Smolik compared alternative, conventional, and ridge-till production systems under various rotations. The alternative system did not use synthetic fertilizers or pesticides. Systems were compared over four years for row crops and also for small grains. In both cases, the alternative system had the lowest net income in the first three years and produced the highest net income in the fourth year, when a drought occurred. Rader et al. report the results of a study undertaken in 1981 to compare the economics and production of conventional and organic peach farming in Utah. Farm budgets indicated that while organic inputs were more expensive, higher prices obtained from these products more than compensated for input costs. Gross income per hectare for organic peaches ranged from $9.64 to $29.60, and $6.90 to $18.50 for conventionally grown peaches. Sahs, Helmers, and Langemeier examined the profitability and net-return stability of continuous corn and five rotation systems and organic vs. nonorganic systems. The net returns from the rotation and organic systems were higher than the net returns from continuous corn. Rotation alternatives had more stable net returns than organic alternatives.

Dabbert and Madden used a multiperiod linear programming model to study the profitability of a beef/crop farm in Pennsylvania undertaking a transition from conventional to organic production practices. After adjustment had been completed, net farm income had declined by 7.3%. Larger losses were incurred during the transition period. Stonehouse and Narayanan compared the costs of a livestock-manure-based fertilizer system with commercial fertilizer. The costs of the manure-based system were lower, but manure provided only 95% of the phosphorous and 70% of the potassium needs of the crops grown. Also, crops grown with the manure-based system provided only one-third of the nutrients needed by livestock.

Olsen, Langley, and Heady, and Langley, Heady, and Olsen analyzed the aggregate effects of widespread adoption of organic production practices in the U.S. Prices for wheat, corn, and other feed grains were projected to be three times the price level achieved under conventional practices. Costs rose somewhat under the organic production system, but not enough to offset the price increases, so overall farm-sector income doubled. Certain regions within the U.S., however, fared better than others under the organic production scenario.

Alternative Production Systems

Alternative production systems represent an intermediate step between conventional and organic systems. Alternative rotation systems and alternative systems to summer fallow have been the predominant type of system evaluated. However, innovative crop rotation systems have also been studied. Similar to the comparison of profitability of organic versus conventional production systems, one system has not consistently outperformed the other in the studies summarized in this section.

The use of summer fallow as a moisture-conservation and weed-control practice has been extensive in grain production on the North American prairies. Summer fallow has, however, been identified as contributing to erosion as topsoil is left bare for extended periods of time. Schoney and Thorson examined the profitability of using crop rotations in place of summer fallow. Unless commodity prices rise dramatically, or in the case of exceptionally good management, summer fallow was found to be more profitable. Young and van Kooten demonstrated that flexible spring cropping systems resulted in higher expected profits, but also higher profit variability than transitional winter wheat fallow rotations. Bole and Freeze compared the predicted yields and economic returns for flexible cropping systems with those of continuous barley and rotations of barley fallow. Basing cropping decisions on available soil moisture returned $14.33/ha more than continuous barley and $22.08/ha more than a barley-fallow rotation. Income variability was lowest for the barley-fallow rotation, followed by the flexible rotation and then continuous cropping.

Lazarus, Hoffman, and Partenheimer studied the returns to farm operator's labor and management for selected cropping systems on dairy farms on better cropland in Pennsylvania. Continuous-corn yields were 10% below yields of corn grown in rotation with alfalfa. However, on small farms, continuous corn was one of the most profitable rotations due to its low machinery costs per acre. For larger farms, the rotation of two years of corn followed by three years of alfalfa gave the highest returns. No-till corn planting increased returns over conventional tillage where tillage equipment can be eliminated or reduced in size. This may not be possible, however, due to equipment requirements of other crops.

Zavaleta et al. used crop enterprise budgets to compare eighteen different treatments consisting of three levels of pest management (high, medium, and low) and two tillage systems (conventional or reduced) for continuous corn, continuous soybeans, and corn-soybean rotations in Illinois. Management alternatives were compared on expected returns, crop yields, and income variability. Generally crop yields increased with increasing levels of pest management when costs were not considered. When costs of production were considered, average expected returns were highest for systems with medium to low levels of pest management regardless of the tillage system used. The corn-soybean rotation under conventional tillage with a low level of pest management produced the highest average net return of $153.50/acre. However, a corn-soybean rotation under reduced tillage with medium or low pest management produced average net returns of $150.77/acre and $150.43/acre, respectively. Corn and soybeans in rotation also produced the least variability in returns regardless of tillage method under low and medium levels of pest management.

Lazarus and White used a linear programming model to investigate the economic impacts of crop rotations on a typical Long Island potato farm. With potatoes limited to being grown one year out of two, returns above variable costs were 61% of the optimal plan with all acreage planted to potatoes. McQueen, Shulstad, and Osborn found that net returns to Arkansas farmers would increase by 28% by changing to crop rotations that lower soil loss. Helmers, Langemeier, and Atwood compared thirteen cash-crop production systems characteristic of east-central Nebraska. Data were obtained from experimental station trials from 1978–86. Net returns per acre, adjusted for inflation, were computed for each system for each year. Seven of the systems represented continuous-cropping systems. Various measures of income risk were constructed, including standard deviation, skewness, coefficient of variation, and the number of years that net returns fell below $100/acre. Rotation systems included corn-soybean-corn-oat/sweet clover rotations with and without the use of synthetic fertilizers and herbicides. Corn-soybean and a grain sorghum–soybean rotation system dominated in terms of expected return and risk. Among the four-year rotation systems, chemical treatments had little effect on average returns or risk, but average returns were less than two-thirds of those of the corn-soybean or grain sorghum–soybean rotations. Zentner, Lindwall, and Carefoot evaluated the economics of producing winter wheat in two-year, three-year, and continuous-crop rotations for a seven-year period using zero tillage and two methods of conventional tillage. Zero-tilled treatments generally outperformed conventional tillage in years with below-normal rainfall and high prices. Under these same conditions, the two- and three-year rotations were better than continuous wheat. Baffoe, Stonehouse, and Kay used a multiperiod linear programming model to compare the long-term profitability of erosion-reducing cropping systems and rotations for southwestern Ontario conditions. Continuous corn was found to be the most erosive, but also the most profitable system.

Crowder et al. used the Chemical Runoff and Erosion from Agricultural Management Systems (CREAMS) model to estimate chemical and soil losses from a representative Pennsylvania dairy farm. The linear programming model optimized net farm income subject to economic and environmental constraints. Three combinations of corn-alfalfa rotations with conventional, reduced, and no-till systems were analyzed. Losses of soil, P, and N, were less for reduced tillage compared to conventional tillage, and for no-till compared to any other system. When no technical or environmental constraints were imposed, a conventional and reduced-tillage system with continuous corn give approximately equal and highest returns, although P and N losses from the reduced tillage are substantially less. With constraints imposed on soil, N, and P loss, a corn-alfalfa rotation under no-till was the most profitable. In addition, returns from this system are equal to conventional tillage under no constraints.

Summary

It is difficult to conclusively determine from the studies summarized the relative profitability of conventional, organic, and other alternative production systems. Results of studies have depended on variations in the production system studied, crops produced, year-to-year variations in weather, soil type, and assumptions of price and cost structures. Studies that have compared the performance of conventional and alternative production practices by changing one component at a time have been criticized for failing to reflect the interactions among elements of a crop production system. Studies that have studied production at a system level, however, have proven to be difficult to interpret. It is not easy to determine what makes one system perform better than another when many variables change across systems.

Conclusions

The published literature on economic dimensions of the interface between agricultural production systems and environmental quality continues to expand rapidly. This review, while seeking to be a comprehensive treatment of the North American literature, has illustrated that while much has been discovered by economic researchers in this area, there is much that remains unknown. It is possible, however, to draw several general conclusions based on our review of the papers included in the references that accompany this report.

We know much more about the costs of restrictions on the production practices of farmers than we know about the value of environmental and human-health benefits obtained from these control actions. This imbalance is a serious impediment to the development of sound policy and suggests an urgent need for research on the benefits of environmental protection.

At the margin, there are trade-offs among competing environmental and human-health objectives, as well as between those objectives and the economic viability of farm firms and the standard of living of consumers of food. These trade-offs are not well understood nor are they adequately documented. They are also not recognized in many policy actions. Many studies that have addressed the on-farm impact of environmental protection policies aimed at agriculture have failed to consider the range of emissions-control policies that have been employed in other sectors (see Hahn or Baumol and Oates). In particular, much of this work has neglected the relationship between property rights and environmental protection (Dales) and the implications of changes in liability rules on incentives to control emissions (see Rothbard). Most authors have only considered the imposition of direct regulatory control in the form of restrictions or outright prohibitions on the use of particular inputs or production practices. Future work in this area would benefit greatly from a broader appreciation of the environmental policy literature produced by economists working in other sectors.

The financial performance of so-called alternative production systems, relative to prevailing modes of production of agricultural commodities, depends on a number of site-specific and farm-manager-specific parameters and the level of commodity prices. Consequently, a production system designed with the intent to control pest populations, soil erosion, or water contamination while maximizing profit will vary significantly from year to year and location. Such a system generally does not consist of one particular production practice but a combination of production practices. Determining optimal production systems has been shown to be difficult since variables are not comparable over systems. Furthermore, the comparative income risk of alternative systems is an important, but often neglected dimension of their performance.

Much of the focus of policy actions to modify agricultural production systems in North America has been on the long-term productivity effects of erosion. The value of environmental consequences of eroded sediment has been neglected in relative terms. As a result, the range of control strategies and policies that have been considered as options for addressing this problem has been too narrow. The available evidence suggests that the off-site impacts from erosion in North America are considerably larger than the on-site long-term productivity effects. From an economist's point of view, it is also important to emphasize the considerable differences in the incentives facing farmers regarding off-site versus on-site effects of erosion. As Fox and Taff (Section 5 in the references) have argued, farmers face considerably stronger incentives to worry about the on-site effects than they do regarding off-site effects. These differences in the nature of incentives have not been fully appreciated in many policy actions.

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Conservation Tillage and Soil Erosion

Conservation Tillage

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