A CEEPES Evaluation of Sustainable Agricultural Policies for Iowa's MSEA Site, Walnut Creek

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Working Paper 94-WP 126
November 1994

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Journal Paper No. J-15938 of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa, Project No. 3291. Paper prepared for the community investment program, "Profitable Stewardship: Agriculture and the Environment," of Pioneer Hi-Bred International, Inc. The authors extend their appreciation to Jerry Hatfield, Director, National Soil Tilth Laboratory, Iowa State University, for his help and for sharing the data. The EPA's support for model development under Cooperative Agreement CR-816099-0101 is acknowledged.

ABSTRACT

Contamination of the nation's ground and surface water supplies from normal use of pesticides and fertilizers has caused growing concern about the impact of agricultural practices on water quality. Informed decisions on sustainable agricultural policies to protect soil and water quality, and also to minimize economic stress to the producers, requires integrated economic and environmental research designed to study the complex interaction of soils, weather, hydrology, chemicals, economics, and other farm management factors. The concept of studying the effects of current and emerging agricultural practices in relation to soil, weather, and management was initiated within five key Midwest sites called Management System Evaluation Areas (MSEA). Using the Comprehensive Economic and Environmental Modeling System (CEEPES), this paper evaluates six alternative sustainable agricultural policies at the Iowa MSEA site, Walnut Creek. CEEPES is an integrated modeling system capable of evaluating the economic and environmental consequences of alternative policies affecting pesticide use.

The alternative policies evaluated against the baseline calibrated to prevailing practices in the study watershed provide useful information on economic and environmental trade-offs for making informed policy decisions on agricultural nonpoint source pollution. Key results on the impacts for crop rotation, crop and tillage mix, profits, and key environmental indicators such as soil loss, nitrate-N leaching/runoff and corn herbicide exposure indices in ground and surface water are summarized. A major finding is that it is possible to achieve voluntary adoption of more environmentally sound practices if producers are compensated with "green payments." The value of the simulations is to provide estimates of the necessary size of these payments and the associated environmental impacts. The multiple environmental indicators show that there are intrinsic trade-offs for sustainability that have to be carefully considered in the final decisions on sustainable policies.

A CEEPES EVALUATION OF SUSTAINABLE AGRICULTURAL POLICIES FOR IOWA'S MSEA SITE, WALNUT CREEK

Contamination of the nation's ground and surface water supplies from the normal use of pesticides and fertilizers has caused growing concern about the impact of agricultural practices on water quality. While field applications of chemicals are not the only source of contamination, the detection of agricultural chemicals in ground and surface water has called for increased focus on the impacts of current agricultural practices. The variety of factors—including weather, soil, and agricultural practices—that affect agricultural chemical loadings to ground and surface water require a very large information base for policy decisions at the national or state level. Furthermore, the geographic variability in risk is likely to make national use restrictions on agricultural chemicals socially and economically inefficient (6). This suggests the need for targeting sustainable agricultural policies. Targeting requires integrated economic and environmental research evaluation, designed to study the complex interaction of soils, weather, hydrology, chemicals, economics, and other farm management factors, within compact watersheds (10). The goal is that these assessments will lead to socioeconomic, and environmentally sound adaptations of current agricultural practices.

The President's Initiative on Enhancing Water Quality is the major program to assess the effects of management practices on water quality and improve them where necessary. To achieve the Initiative's goal, the concept of studying the effects of current and emerging agricultural practices in close relation to soil, weather, and management conditions was initiated within five key Midwest sites—Management System Evaluation Areas (MSEA). The specific regional objectives of the MSEA projects are: (1) **measure** the impacts of farming systems on water and ecological resources; (2) **identify** the factors and processes that control fate and transport of agricultural chemicals and identify alternative management systems that protect water and ecological resources; and (3) **evaluate** the socioeconomic impacts of alternative farming systems. The wealth of information generated in these MSEA sites will be of value for studying the impacts of sustainable agricultural policy targeting.

Sustainable agricultural policies inherently reflect a trade-off between the need for production practices that minimize the costs of production and control of agricultural chemicals that are introduced into the environment by those practices (7). Besides producing bountiful crops, agricultural activities can sometimes lead to soil erosion, pesticide and nutrient contamination in ground and surface water, worker exposure to pesticides, and pesticide drift. Adverse impacts include loss of ecosystems and their functions, public uncertainty about the safety of the food and drinking water supplies, declines in plant and animal number and diversity, and reduced soil fertility. On the other hand, regulations or controls can have undesired economic effects: incremental loss of pesticides leading to increased costs to producers, higher prices of agricultural products for consumer goods, and reduced export earnings from agricultural products. Unintended adverse environmental effects can even occur if policies to protect ground and surface water quality from pesticides result in increased soil erosion and sediment loadings to surface water. Therefore, it is essential that analytical tools allow policymakers to evaluate policies and practices both for the needs of commodity production and protection of the environment.

Using the Comprehensive Economic and Environmental Modeling System (CEEPES) developed by the Iowa State University's Center for Agricultural and Rural Development under a cooperative agreement with the U.S. Environmental Protection Agency (EPA), this paper evaluates six alternative sustainable agricultural policies at the Iowa MSEA site—Walnut Creek. CEEPES is an integrated modeling system capable of evaluating the economic and environmental consequences of alternative policies affecting pesticide use. CEEPES integrates diverse simulation models within four major components—policy, agricultural and economic decisions, fate and transport, and health and ecological risk. In this study, the economic and environmental parameters of the CEEPES system were calibrated with the observed data from the Walnut Creek watershed. The alternative policies evaluated against this baseline provides useful information on economic and environmental trade-offs for making informed policy decisions on agricultural nonpoint source pollution (NPS). Key results on the impacts for crop rotation, crop and tillage mix, profits, and key environmental indicators such as soil loss, nitrate-N leaching/runoff, corn herbicide exposure indices in ground and surface water are summarized.

The CEEPES Integrated Modeling System

The EPA has traditionally responded to evidence of unreasonable health or environmental risks associated with agricultural chemicals through regulations and use restrictions. EPA's Scientific Advisory Board, which reviewed the Relative Risk Reduction Project, however, recommended that greater attention be paid to ecological problems associated with agricultural NPS pollution (12). As a result the current EPA program may no longer be defensible as a way to manage water-related risks from agricultural chemicals. Given the need to consider the complexity of water quality issues when assessing the risks and benefits of agricultural chemical use, EPA funded the development of the assessing the risks and benefits of agricultural chemical use, EPA funded the development of the CEEPES system to study corn and sorghum pesticide policies in the midwestern United States.

CEEPES simulates risk-benefit trade-offs associated with NPS pollution from agricultural production. It links biophysical with economic modeling systems that have been integrated over the dimensions of time and space. Four components constituting the conceptual structure, illustrated in Figure 1, provide the necessary flexibility for model and policy integration: policy specification, fate and transport, agricultural decisions, and evaluations of environmental and human health benchmarks and economic impacts. To ensure congruence of temporal and geographic scale, "experiments" with calibrated geophysical process models produced response surfaces (metamodels) that have statistical integrity and known experimental and sampling error (6).

Various factors influence the domain of natural phenomena to produce measurable outcomes of policy interest. A computer physical process model simulates the phenomenon for a specific environmental medium or activity. Because the time steps and area over which the phenomena are simulated by a model differ according to the medium or activity for which they occur, the outcomes generated by one model specific to a particular medium cannot easily be related to those of another. Therefore, integration of the system, whereby an economic activity is temporally and spatially linked with physical phenomena, involves consistently and robustly linking component models and aggregating the results into regional indicators of risk and benefits. Metamodels, statistical models of the actual simulation models, play a major role. Metamodel linkages eliminate the need for redundant simulations of process models for each policy scenario, saving time and money.

The CEEPES system characterizes weed control technologies, resulting in the construction of more than 400 alternative weed control strategies for corn production, and more than 100 strategies for sorghum. These strategies are designed to control both grasses and broadleaf weeds. Each strategy includes a primary and a backup treatment (to deal with weeds that survive the primary treatment), a set of herbicides applied individually or in tank mixes, a tillage practice (no-till, reduced, and conventional), chemical application rates, an application mode (broadcast, incorporated, banded), a timing of application (early preplant, preplant incorporated, preemergent, postemergent), and temporal windows of application and effectiveness for both primary and secondary strategies. Thus, a ban on a particular herbicide does not simply imply a chemical-for-chemical substitution, but rather selection from among an entire array of weed control strategies that are potential substitutes. In addition, production risk is incorporated into the modeling system by simulating the impact of weather uncertainty on dates of chemical application and the resulting effectiveness. This approach is embodied in WISH (Weather Impact Simulation on Herbicides) (3).

Components of CEEPES

The information flow and configuration of the system are shown in Figure 2. Policy and regulatory options affects the range of strategies available to the producer. The system is configured to allow simulation of policy interventions restricting or enhancing producer behavior with regard to production decisions. The Resource Adjustment Modeling System (RAMS) is a linear programming model that simulates the profit-maximizing decisions of producers. Producers choose an optimal mix of crop and crop rotations, chemical inputs, labor, tillage, and other factors to maximize net return. The WISH model identifies the most efficient weed control strategies for corn and sorghum based on timing and method of application, efficacy of chemical combination, and tillage. Agricultural Land Management Alternatives with Numerical Assessment Criteria (ALMANAC) is a process model that simulates crop growth, weed competition, and the interactions of management alternatives. The fate and transport models estimate loadings and concentrations of contaminants in the various environmental media, such as water and air. These concentrations are then either summarized directly as a ratio to health or environmental benchmarks or as a frequency that a benchmark is likely to be exceeded under any estimated scenario. The models that compose the various components are described in detail in conjunction with the component in which they function.

To date, the CEEPES system has been used to evaluate corn and sorghum herbicide policy options (4) and also corn rootworm insecticide analysis. In addition to the herbicide policy analysis, CEEPES has been used in a global climate change study dealing with economic and resource impacts of policies designed to increase carbon sequestration. One of the most important aspects of CEEPES is a detailed characterization of weed control technology which, in addition to standards and control measures like bans, rate restrictions, and timing restrictions, can lend itself to the evaluation of incentive-based options such as best management practices, and taxes on chemical inputs. Because of the detailed production technologies, CEEPES is also well suited for watershed-level analysis and for evaluating the costs and benefits of best management practices.

Key problems that had to be overcome in applying CEEPES to a large region include the wide variation in temporal and spatial scales of different models requiring special interfaces; difficulties aggregating field-scale model output to larger geographic areas; the lack of adequate calibration and validation data for models; the lack of detailed data on chemical applications, yields, and producer risk; and the need for diverse soil and weather data sources. The consequence of these problems is that CEEPES is appropriately used only for analyses of relative shifts of policy alternatives from the baseline. Improved coordination between USDA and EPA with regard to data specification and development could improve accuracy and facilitate the use of CEEPES for other crops and regions.

Environmental Fate Component

Chemical Leaching. Herbicide leaching in the soil root and vadose zones was simulated with the PRZM and VADOFT components of the EPA's RUSTIC model. The PRZM (Plant Root Zone Model) component of RUSTIC partitions the mass of the pesticide into amounts available for volatilization, runoff, and leaching. The amount available for leaching becomes the input into the VADOFT component that moves the mass from the root zone through the vadose zone. We did not estimate lateral flow with RUSTIC. Statistical sampling of soil, climatic, pest management, and chemical parameters representative of the study region were used as inputs to RUSTIC to estimate groundwater concentrations. Thus, using statistical procedures, we select a sufficient number of data for each key variable, that affect the concentrations in groundwater to achieve the desired level of statistical accuracy and reliability. We then estimate peak and average pesticide concentrations at depths of 1.2 and 15 meters, which are assumed representative of vulnerable, shallow groundwater and are typical depths for the water table and rural domestic drinking water wells in the study area. Nitrate-nitrogen leaching, from nitrogen fertilizer application at optimal rates, below the soil root zone was simulated with EPIC (Erosion Productivity Impact Calculator) developed by USDA (9).

Chemical Runoff. Edge-of-field pesticide loadings from RUSTIC serve as input into the STREAM methodology to estimate chemical concentrations in surface water. STREAM is a screening-level tool for estimating in-stream solution and stream bed concentrations. It is based upon 10-year simulation runs of the HSPF river basin model for representative watershed of four main crop producing areas. STREAM estimates are generally within a factor of 10 of actual monitoring values. The surface runoff of nitrate-nitrogen for alternative crop and management practices was also simulated with EPIC. Simple response functions developed for EPIC outputs on nitrate-nitrogen leaching/runoff using metamodeling technique served as the tool for evaluating nitrate-nitrogen concentration under alternative policies.

Soil Erosion. Soil degradation from sheet and rill erosion estimated by the Modified Universal Soil Loss Equation (MUSLE) was used in estimating soil loss from alternative crop and management practices. Wind erosion was not measured because of negligible wind effect in the study area.

Agricultural Decision Component

Input Substitution Model. The WISH model simulates the efficacy and cost of alternative weed control strategies for corn and sorghum. It simulates likely weed control management based on herbicide efficacy, weather conditions, timing and effectiveness of application, mode of application, soil texture, targeted weeds, and observed farming practices. Examples of weed control strategies for different tillage systems are shown in Table 1.

Economic Behavior Model. RAMS integrates the information on policies affecting pesticide use and on farmer pest control strategies to simulate economic behavior for the system. It is a regional, short-term, profit-maximizing, linear programming model of agricultural production, defined at the Producing Area (PA) level. PAs are hydrologic regions representing aggregated subareas defined by the Water Resources Council (13). There are 105 PAs in the continental United States. RAMS estimates the economic impact of alternative agricultural and environmental policies in terms of acreage planted, rotation, tillage practice, chemical input, net return, yield, and cost of production for all PAs in the study region.

Benefit-Risk Characterization

The chemical concentration levels found in surface and groundwater are transformed into a unitless measure of risk that we call an *exposure value*, whereby pesticide-specific benchmarks for human health and aquatic habitat are used to weight the relative importance of pesticide concentrations. The term *exposure value* is used to prevent confusing such values with estimates of absolute risk. Instead, their purpose is solely for comparing policies and practices and serving as rough indicators of water quality. Using a benchmark for environmental hazards, such as drinking water Maximum Contaminant Levels (MCLs) for long-term exposures and ten-day Health Advisories for short-term exposures, we calculate the exposure for each chemical as:

$$\text{Exposure Value (hazard-weighted exposure)} = \frac{\textit{predicted concentration}}{\textit{environmental benchmark}} .$$

The exposure value normalizes concentration levels, thereby allowing us to compare risks across herbicides and across policies. If the exposure value exceeds unity, the concentration exceeds the benchmark. This ratio of predicted concentration to human health or ecological benchmarks is used as the measure of risk of adverse impact from environmental exposure. The greater this ratio is, the greater the risk that we would predict for exposure to a particular pesticide. Any value approaching or exceeding unity is of concern. The decision maker must, using chemical-specific information, determine whether or not the risk depicted in the baseline scenario is of sufficient magnitude to warrant action. CEEPES can only assist in determining whether or not any policy to address the risk in the baseline is likely to improve or worsen the overall environmental impact.

Since pest control strategies often need more than one pesticide in a tank mix, and since different farmers use different strategies and hence pesticides, surface water may contain a mixture of pesticides at any given time. Ground and surface water may also contain a mixture of pesticides where a variety of pest control strategies has been used over a number of years. For the purpose of comparing policy alternatives, we characterize the risk associated with exposure to these pesticide mixtures in a particular medium by adding the ratios of predicted concentrations to benchmarks for each pesticide in the mixture (referred to as *sum exposure*), in accordance with EPA guidelines on assessing risk from chemical mixtures. A final risk value for a category of environmental impacts, human health as opposed to ecological, for a particular policy is determined by assigning a weight, or a measure of relative importance, to each medium of exposure.

Balancing environmental risks with the benefits that accrue from pesticide use therefore involves weighing the risks associated with one medium or to one receptor with those associated with other media or receptors and trading off benefits for reductions in one or more impacts. These trade-offs often concern objects of dissimilar nature or risks of different duration or severity. Where options or choices present different types of risk and hence are not directly comparable, value judgments must be made about their relative importance. Should economic gain be weighed against environmental risk? How should threats to ecological habitats be weighed against risks to humans? Consensus can more easily be reached on how these decisions should be made if: (i) technical and professional estimates are clearly separated from value judgments, and (ii) value judgments are appropriately made by policymakers to whom the responsibility of political judgment has been given.

The Study Area

The Iowa MSEA project will quantify the levels of nitrate and pesticides and their movement in soils according to climate, crops, and varying management practices. The Iowa MSEA experiments are carried out at three sites throughout the state (8). Each site represents a different geologic, hydrologic, climatic, and agricultural setting. The sites are located near Treynor on the rolling loess hills in Major Land Resource Area (MLRA) 107, Nashua on the thin glacial till in MLRA 104, and Des Moines lobe area near Ames on the thick glacial till soils in MLRA 103.

For this study, the focus is on the Walnut Creek watershed in the Des Moines lobe area of Central Iowa (Figure 3). The Des Moines lobe area is characterized by Wisconsin till deposits overlying Pennsylvania shale and sandstone formations, and the presence of prairie potholes. The soils are part of the Canisteo-Clarion-Nicollet-Webster association with flat terrain, and are typically poorly drained and high in organic matter and native fertility. The average annual precipitation in this site is around 849 mm. There are 13,100 acres of crop and pasture land in this watershed. Walnut Creek is an intensively farmed watershed with more than 95 percent of the cropland in row crops. Corn and soybeans are the two major row crops, comprising of 52 and 43 percent of total cropland. The average yield of corn and soybean recorded in 1991 was 125 and 45 bushels per acre, respectively. The prevalent tillage practices in this watershed include conventional tillage (73%), reduced tillage (fall chisel-plow) (25%), and no-till (2%). Forty percent of the corn acres are "base acres" qualifying for the commodity program participation, and the Conservation Reserve Program (CRP) acres are negligible.

In 1991, 694,000 pounds of nitrogen (N) were applied to the crops grown in the area. Fertilizer practices range from fall-applied anhydrous ammonia, to split-application of liquid N, to swine manure. More than 95 percent of the corn acres are treated with herbicides, and there were an average of 1.8 herbicide treatments per acre. Atrazine, cyanazine, EPTC, and metolachlor accounted for nearly 75 percent of the corn acres treated with herbicides. The chemical practices range from broadcast to banded preemergence and postemergence on no-till.

The agricultural economic decision model was calibrated to the Walnut Creek watershed to evaluate the socioeconomic and environmental impacts of alternative policies. The model was configured to allow simulation of policies modifying producer behavior and production decisions. It is a linear programming model simulating the short-term profit-maximizing decisions of producers. The input and output prices are exogenous, meaning that the model does not get feedback on price impacts resulting from policy-induced changes in production. Therefore the policy impacts are strictly short-term in nature. The long-term or dynamic impacts will be comparatively smaller. By constructing a decision making model for the entire watershed, which has many producers, we assume that the cropping and management practices represented in the model are average responses. Producers choose an optimal mix of crop and crop rotations, chemical inputs, labor, tillage, and other factors to maximize net returns to crop production. Corn, soybeans, oats, winter wheat, sorghum, corn silage, and legume hay are the alternative crops available for choice. The range of crop rotation systems included in the model are: *continuous corn, corn-soybean, corn-corn-soybean, corn-corn-soybean-oats-legume hay, corn-oats-winter wheat, corn silage-soybeans, corn silage-soybeans-legume hay, and corn-corn-corn-oats-legume hay*. The model simulates four different tillage practices: conventional tillage with fall plow, conventional tillage with spring plow, reduced tillage, and no-till, which are defined by the amount of residue cover.

The WISH model identifies the most efficient weed control strategies for corn and sorghum based on timing and method of application, efficacy of chemical combination, and tillage. The model baseline was calibrated to the 1991 levels of production, prices, and resource use, including the government programs. The government sub-sector of the model includes 7.5 percent Acreage Reduction Program (ARP) and 15 percent Normal Flex Acres. A new provision in the 1990 Farm Act is that farmers may plant crops on the 15 percent of Crop Acreage Base that are not eligible for payments without loss of Crop Acreage Base. The deficiency payments and the CRP payments are estimated at the current rates, which are calculated based on the county level average payments.

The Policy Options and Results

One of the objectives of MSEA is to evaluate the socioeconomic and environmental impacts of alternative sustainable agricultural policies. The current policy focus of the EPA and USDA depart from the traditional supply oriented and acreage reduction policies. The new and evolving policies aim at making current agricultural practices more sustainable and environmentally sound. Figure 4 lists policies that were analyzed, including the baseline or status quo, which is policy 1.

Policy 2 evaluates the economic and environmental impacts of putting a total ban on atrazine application in corn production, and policy 3 imposes an additional 25 percent tax on fertilizers assessed as an equivalent price increase on nutrients. Policies 2 and 3 are market based policies. Atrazine is the most widely used herbicide for corn and sorghum, and one of the most commonly encountered in surface and ground water. In addition to water quality problems, Atrazine poses hazards through air transport, food residues, and the exposure of applicators, and wildlife. Belluck et al. note that the detection rate is 10 to 20 times more frequent than the next most often detected pesticide (2). The detected levels, often exceeding the federal drinking water standard of 3 parts per billion (ppb), have led the EPA and state agencies to review policies to control or ban atrazine use. Current atrazine use in the Midwest is estimated at 52 million pounds of active ingredient, accounting for nearly 12 percent of the total agricultural pesticide use in the United States (11). If atrazine use is restricted, substitute herbicides will come into wider use, imposing different environmental stress, cost or efficiency penalties, and shifts in production and resource use patterns.

Policy 4 is the most restrictive policy limiting the choice of production activities to a single mandated crop rotation—*corn-corn-soybean-oats-hay*. It is a major sustainable crop rotation requiring reduced chemical and nutrient application, and it preserves year-round cover. Policies 5 (reduce soil loss by 25 percent of the baseline) and policy 6 (reduce nitrate-N leaching by 50 percent of the baseline) are the *first-best* policy options in terms of targeting, but they require more costly information and monitoring. Policy 7 allows 25 percent option flex acres. Under the 1990 Farm Act, farmers wanting greater planting flexibility than the 15 percent of base, which is normal flex acres could use up to an additional 10 percent of the crop acreage base as optional flex acres, subject to the same planting provisions. If farmers plant other program and permitted nonprogram crops on these optional flex acres, deficiency payments are lost on these acres, but the crop acreage base qualifying for programs is protected. For this simulation it is assumed that the farmer can use up to an additional 25 percent of base as option flex acres.

The Results

The results of these alternative policies are summarized as relative changes from the baseline. Key results on the impacts for crop rotation, crop and tillage mix, profits, and some environmental indicators such as soil loss, nitrate-N leaching/runoff, herbicide exposure indices are summarized. Note these are short-term responses to policy shock and are specific to the conditions prevailing in this watershed. The policy of allowing 25 percent option flex acres had no impact on the baseline production practices, which suggests that even under increased planting flexibility the farmers prefer to grow more corn because it is profitable. This policy only reduces government program payments; and has very little or no environmental benefits unless the choice of crops that the farmers can grown on these option flex acres are also restricted. This policy, certainly, is not a "green program," especially in the Midwest where the options to grow alternative crops are limited because of climatic and soil conditions. Since there is very little impact (or departure from the baseline) with the 25 percent option flex acre policy, it is not included in the ensuing discussions.

Table 2 shows the shifts in crop rotation under other alternative policies. The proportion of acreage in each crop rotation to the total cropped acreage is shown in the baseline column. The changes in the crop rotation shares relative to the baseline are shown for each policy scenario. *Continuous corn* and *corn-soybean* are the two major crop rotations in the baseline. A ban on atrazine increases the share of *corn-soybean* rotation by 10 percent. Production of *continuous corn* and in general production under conservation tillage (reduced- and no-till) declines because they are relatively heavy users of atrazine. On the other hand, increasing the fertilizer price by a 25 percent tax increases the share of *corn-soybean* rotation much more than under atrazine ban policy. *Continuous corn* acreage is completely shifted to a *corn-soybean* rotation, which is a more sustainable agricultural practice since the pest cycles are disrupted, thereby requiring lower pesticide use. Also, the need for commercial N is reduced if farmers give adequate credit for the legume-fixed N.

The impact of N-leaching policy was similar to the fertilizer tax policy, but the N-leaching policy also shifted some of the acreage out of no-till since it is associated with more leaching than the conventional tillage. The crop rotation policy is a mandatory control requiring an almost complete redistribution of the baseline acreage into *corn-corn-soybean-oats-hay* rotation. The soil loss reduction policy increases the share of *continuous corn* because *corn-soybean* rotation is generally more erosive. Also, a shift from fall-plow, which is more erosive, to spring-plow and no-till occurs.

There are recent reports that farmers who used soil-saving tillage practices had more topsoil as well as more dollars. Furthermore, the soil-conserving technologies reverse the off-site damages such as sediment deposition in rivers and stream and reduced chemical runoff. Therefore, it is interesting to study the impacts on tillage from these policies (Figure 5). Three-fourths of the baseline production was under conventional tillage, which compares to the current practices in the watershed. Chemical based policies—atrazine ban, fertilizer tax and N-leaching—shifted production from chemical intensive no-till practices to conventional tillage, showing the trade-off between soil erosion and water quality. Contrary to this result, the soil-saving policy shifts production from conventional tillage to reduced- and no-till practices. The crop rotation policy increased the share of reduced tillage from 16 percent in the baseline to 65 percent, and reduced conventional tillage from 75 to 35 percent. This suggests that for the mandatory crop rotation, chisel plowing (reduced tillage) is more profitable than other tillage systems.

Because of climate and soil induced limitations on the alternative crops for this watershed, the crop distribution impacts were mostly between corn and soybeans (Figure 6). Corn and soybeans account for 58 percent and 38 percent of the total baseline acreage, respectively. Crops such as oats, which are mostly grown as cover crops to utilize the excess moisture and nutrients left in the field after the harvest of previous crops, were least impacted. Next to the mandatory crop rotation policy, the fertilizer tax and N-leaching policies reduce corn acreage the greatest amount (10 to 15 percent). The atrazine ban policy reduced corn acreage by 3 percent. The soil-saving policy increased corn acreage by 6 percent, mainly due to the shift in crop acreage from *corn-soybean* rotation (which is more erosive) to *continuous corn*. At the regional levels the acreage adjustments will be smaller. Atwood and Johnson estimate 0.4 and 0.6 percent decline in corn acreage in the Corn Belt and Lake States, respectively, for a 25 percent increase in N price (1). Furthermore, the model does not account for N supply from livestock manure, which will reduce the corn acreage shift.

The changes in corn and soybean yields are shown in Figure 7. Corn yield decreased by 1 to 2 percent under the atrazine ban and crop rotation policies, and increased by 0.5 to 1 percent under the fertilizer tax, soil-saving, and N-leaching policies. A ban on atrazine eliminated the most efficient weed control strategies (strategies that have minimum yield loss and cost) from the set of strategies available to the farmer, resulting in reduction in corn yield. On the other hand, fertilizer and leaching policies, which favor a *corn-soybean* rotation, benefitted from the increased yield potential of this rotation compared to *continuous corn*. The yield increase under the soil-saving policy was due to the model preferring most efficient weed control strategies. Soybean yields decreased under the crop rotation and soil-saving policies, but the change was marginal under the other three policies.

Finally, the impacts on the key economic and environmental indicators, in addition to the production and management practice impacts, will complete the policy impact analysis (Figure 8). The key economic indicator used in this analysis was profits or net returns to production (gross revenue including government program payments less cost of production) measured in U.S. dollars. The environmental indicators selected were: (a) amount of soil loss per acre, (b) nitrate-N in runoff, (c) nitrate-N leaching, (d) corn herbicide leaching measured by the cumulative exposure value (*sum exposure*) in groundwater at 1.2 meters, and (e) corn herbicide exposure in surface runoff.

With a complete ban of atrazine use on corn, profits declined by $2.21 per acre (2 percent from the baseline); however, there were significant gains to water quality as the *sum exposure* value of corn herbicides decreased for both ground and surface water, and also nitrate-N leaching decreased by about 40 percent. The reduction in sum exposure in groundwater and surface runoff is attributed mainly to a 25 percent overall reduction of corn herbicides as a result of banning atrazine. By banning atrazine, mechanical weed control strategies (rotary hoe and row cultivator) became more efficient wed control strategies, which explains the reduction in total herbicide use. The reduction in nitrate leaching is attributed to a decrease in conservation tillage (reduced- and no-till) acres. But the atrazine ban policy lead to increased soil loss and nitrate runoff. The increased erosion was due to decrease in conservation tillage. To make a final judgement on economically and environmentally sound policy, one has to impute relative weights to the economic and environmental indicators and draw associated inferences. The fertilizer tax policy impacts were similar to those of the atrazine ban policy, except that herbicide exposure impacts were reversed.

The soil erosion and nitrate leaching policies had relatively small impacts on profitability, but the herbicide exposure increased for both ground and surface water. This suggests a trade-off between controlling herbicide contamination of drinking water, the nitrate contamination, and the potential soil loss. The crop rotation policy resulted in the largest reduction in profit (25 percent), but also produced significant gains to soil and surface water quality. The leaching potential increased because of increased conservation tillage, and also the increased production of cover crops (oats and legume hay) contributed to increased leaching. Given the significant reduction in profits that is indicated by the simulation, the farmers would clearly have to be compensated for economic losses to encourage voluntary switch to this sustainable crop rotation.

To make a final judgment on economically and environmentally sound policy, one has to impute relative weights to the economic and environmental indicators and draw inferences based on trade-offs between selected indicators. This, however, is only a second-best approach. Lack of data for imputing a dollar value on environmental benefits/damage prevents us from doing a more general welfare measurement of alternative policies. Figure 9 traces out the trade-off, exhibited by the alternative sustainable agricultural policies, between profits and soil loss, profits and groundwater exposure, and profits and surface water exposure. The groundwater and surface water exposures are the cumulative total of herbicide and nitrate-N exposure in the respective media. The exposures values are the ratio of actual concentrations to the EPA benchmarks for long-term human health exposure (MCLs). The environmental indicators were defined such that it is desirable to be in the Northeast corner of the XY-plane with profits measured along the Y-axis. The points on the trade-off frontier are efficient in a Pareto sense such that the points above the frontier are infeasible and it is always possible to improve at least one objective by moving away from the points below the frontier.

Concluding Remarks

The economic and environmental impacts of alternative sustainable agricultural policies were examined in a geographically targeted watershed—Walnut Creek—providing information for simultaneous assessments of soil and water quality and the socioeconomic impacts of current agricultural practices. A major finding is that it is possible to achieve voluntary adaption of more environmentally sound practices, if producers are compensated with "green payments." The value of the simulations is to provide estimates of the necessary size of these payments and the associated environmental impacts. The multiple environmental indicators show that there are intrinsic trade-offs for sustainability that have to be carefully considered in the final decisions on sustainable policies. Changes in farmer behavior in response to sustainable agricultural policies do not effect all environmental indicators consistently, even in terms of qualitative impacts.

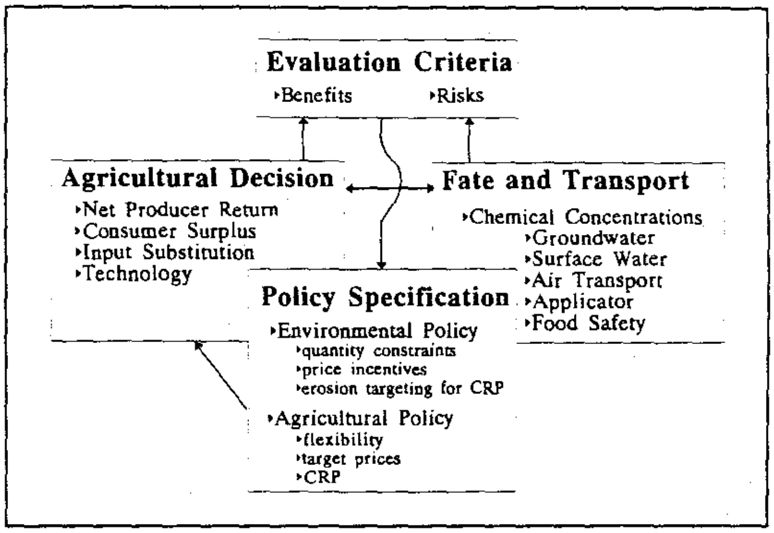

Figure 1. The four components of CEEPES

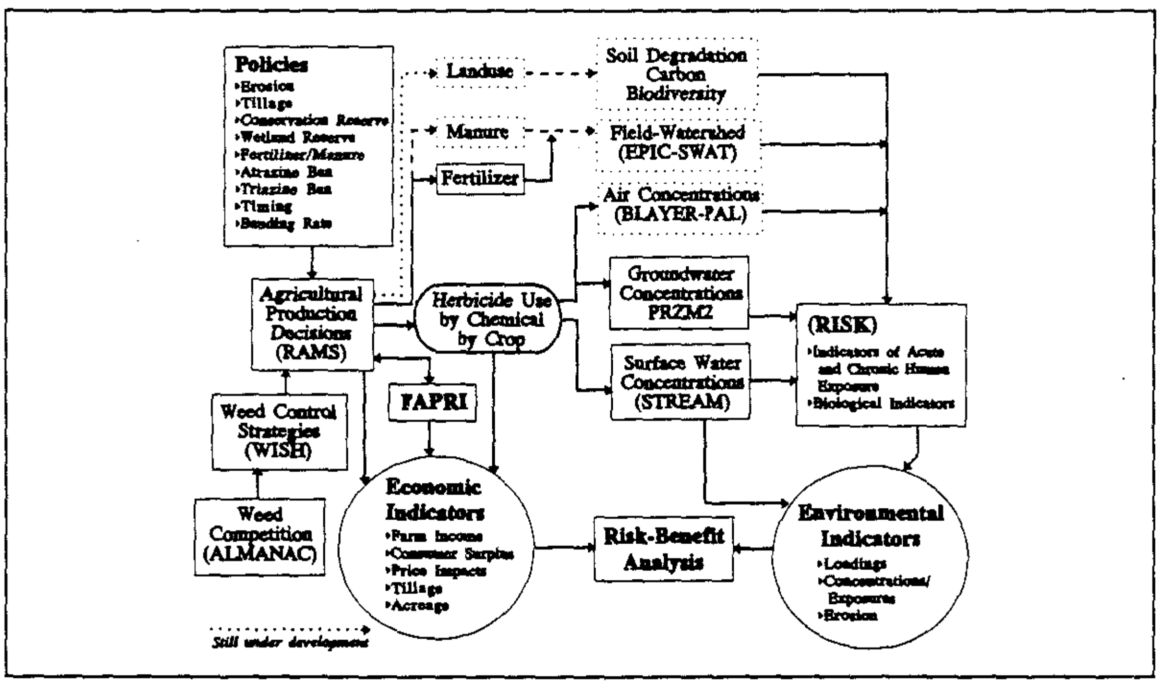

Figure 2. Information flow in CEEPES

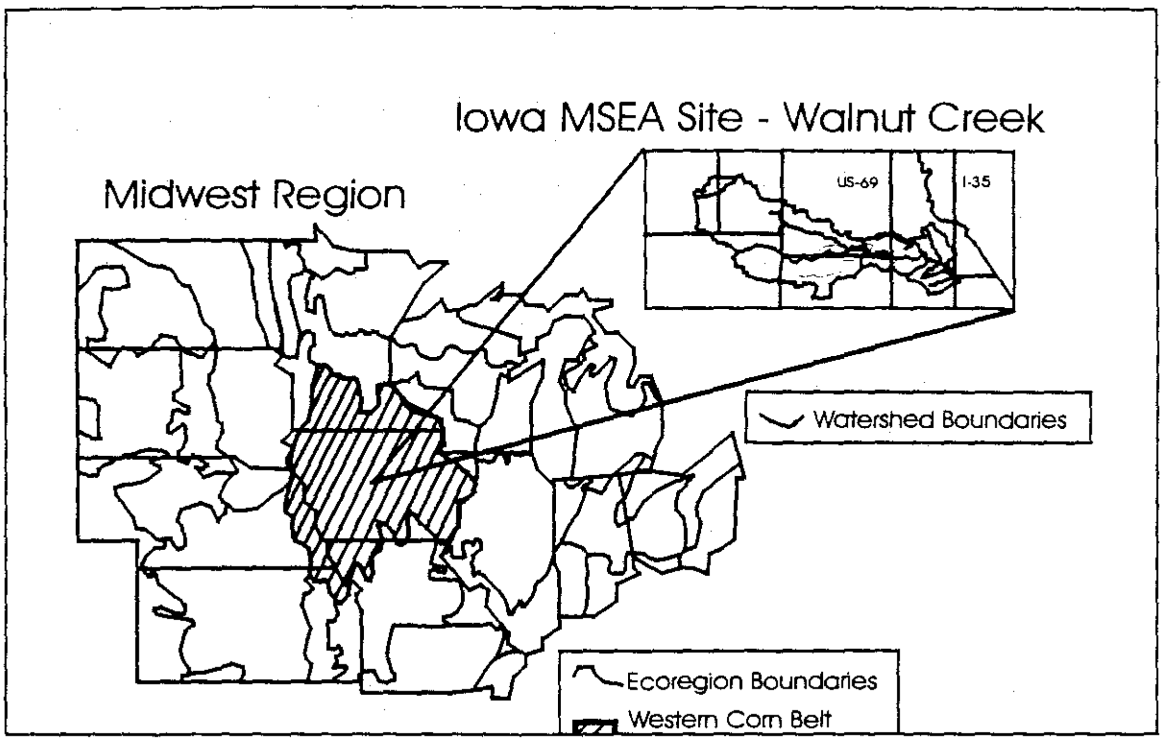

Figure 3. The Walnut Creek watershed

1. Baseline
2. Total bans on atrazine use on corn
   (Atrazine Ban)
3. 25 percent tax on nutrients, NPK
   (25% Fert. Tax)
4. Mandating *corn-corn-soybean-oats-hay* rotation
   (Crop Rotation)
5. Reduce soil loss by 25% of baseline
   (Soil Loss < 25%)
6. Reduce nitrate-N leaching by 50% of baseline
   (N-Leaching < 50%)

Figure 4. The policy matrix

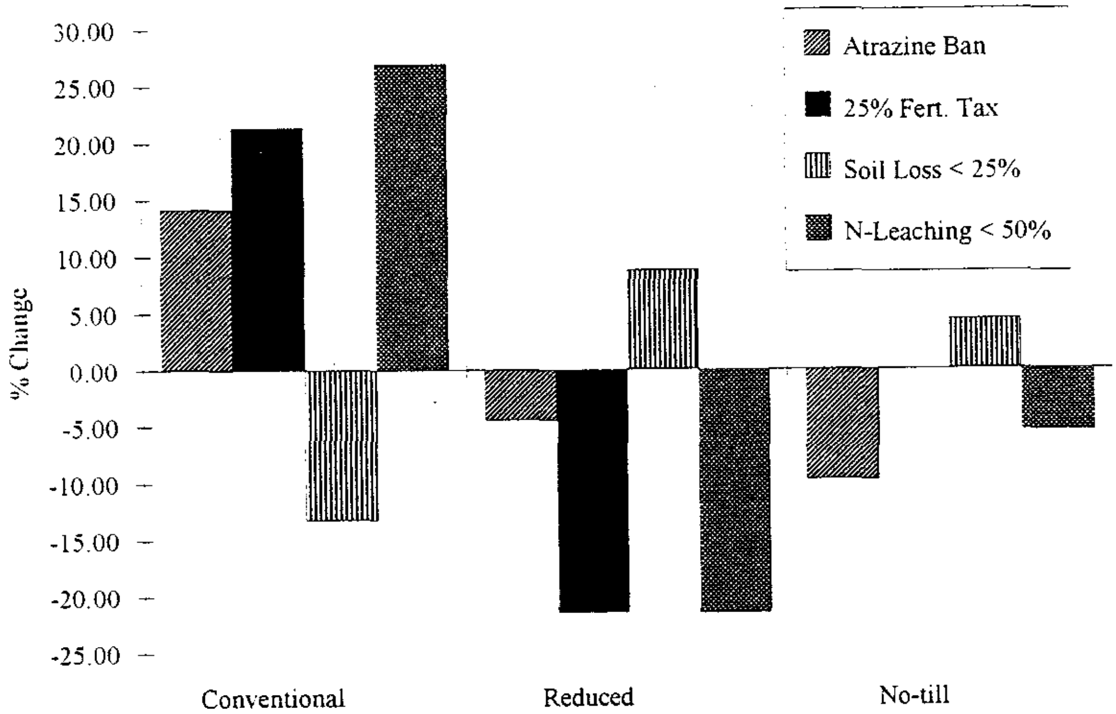

Figure 5. Shifts in tillage

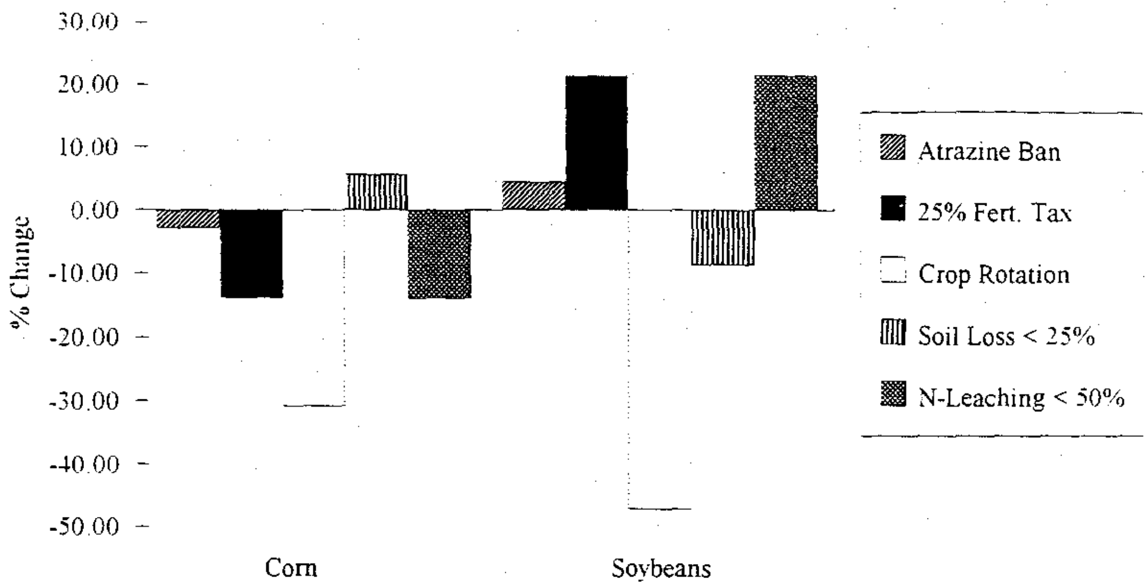

Figure 6. Shifts in corn and soybean acreage

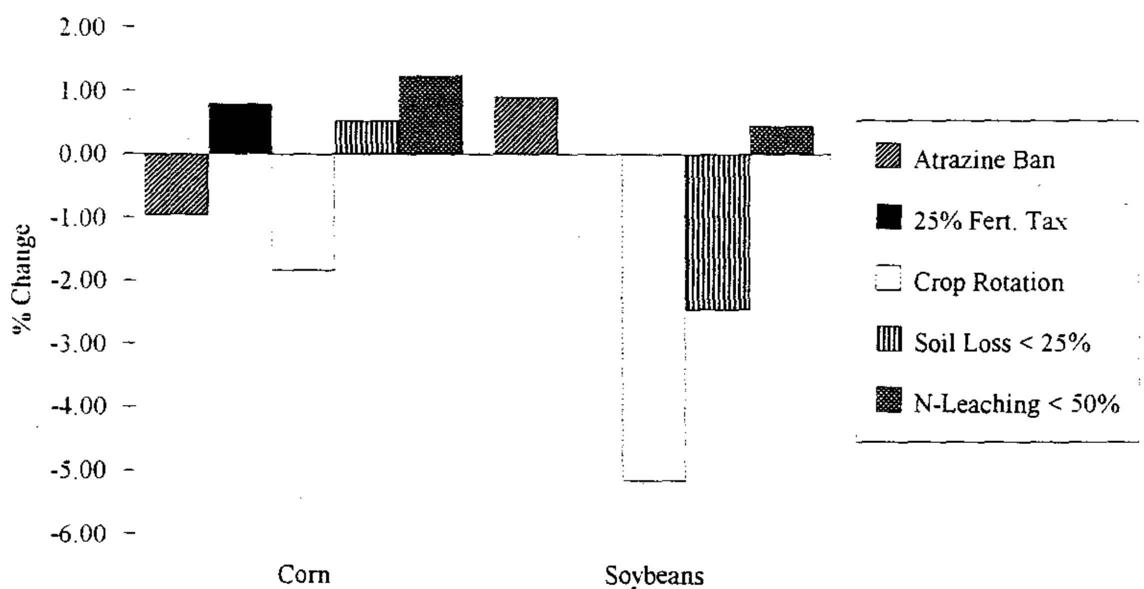

Figure 7. Shifts in corn and soybean yields

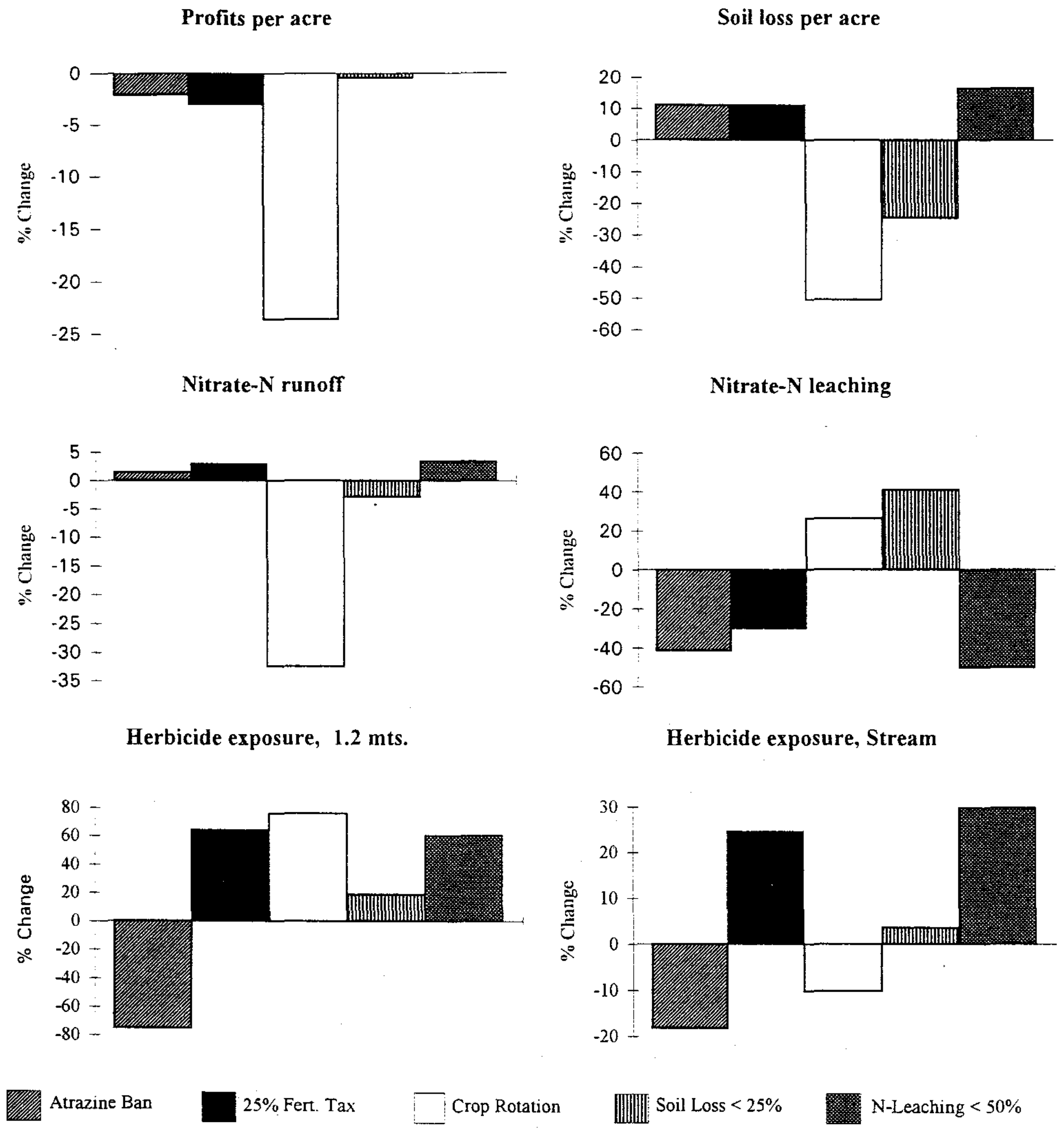

Figure 8. Shifts in key economic and environmental indicators under alternative policies

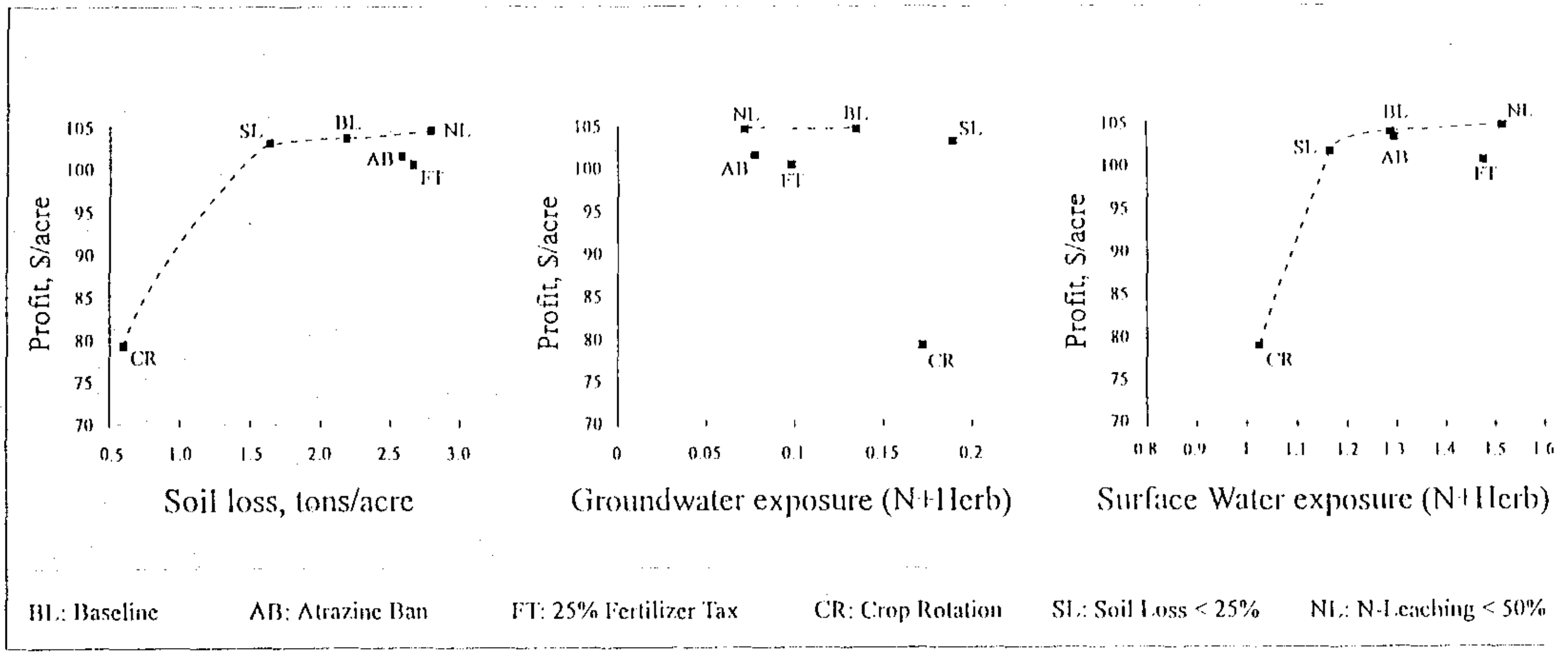

Figure 9. Trade-offs between profitability and soil and water quality

Table 1. Examples of weed control strategies for corn

	Strategy 1	Strategy 2	Strategy 3
Primary Weed Control Strategy	Atrazine-Bladex early preplant[a]	Atrazine-Lasso preplant incorporated[b]	Bladex preemergent
Secondary Weed Control Strategy	Banvel- 2,4-D post emergent	Atrazine[a] postemergent	Accent postemergent
Primary Application Window	4/5-4/25	5/1-5/10	5/10-5/25
Primary Effectiveness Window (B)	77 days	60 days	40 days
Primary Eff. Window (G)	57 days	50 days	50 days
Secondary App./Eff. Window (B)	5/17-6/1	5/17-6/7	6/1-6/20
Secondary App./Eff. Window (G)	N.A.	5/17-5/31	6/1-6/13
Tillage System	No-till	Conventional Till	Reduced Till
Application Technology	Broadcast	Incorporated	Broadcast/Banded

[a]Atrazine applied at a rate > 1.5 lb./acre
[b]Atrazine applied at a rate < 1.5 lb./acre

Table 2. Crop rotation choice under alternative policies

Crop Rotation	Tillage	Baseline Share	Atrazine Ban	25% Fert. Tax	Crop Rotation	Soil Loss < 25%	N-Leaching < 50%
			absolute change in crop rotation share				
CRN	Reduced till	-16.2	-3.4	-16.2	16.2	6.6	-16.2
CRN CRN CRN OTS HAY	Conv.till/spring plow	7	0	0	-7	0	0
CRN CRN SOY OTS HAY	Conv.till/spring plow	0			34.2		
	Reduced till	0			65.8		
CRN OTS WWT	No-till	1	0	0	-1	0	0
CRN SOY	Conv.till/fall plow	68.5	10.7	16.1	-68.5	-56.2	20.3
	Conv.till/spring plow	0					
	No-till	7.4	-7.4	-7.4	-7.4	3.3	-4.2

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