Adoption of Agricultural Production Practices: Lessons Learned from the U.S. Department of Agriculture Area Studies Project. By Margriet Caswell, Keith Fuglie, Cassandra Ingram, Sharon Jans, and Catherine Kascak. Resource Economics Division, Economic Research Service, U.S. Department of Agriculture. Agricultural Economic Report No. 792.

Abstract

The U.S. Department of Agriculture Area Studies Project was designed to characterize the extent of adoption of nutrient, pest, soil, and water management practices and to assess the factors that affect adoption for a wide range of management strategies across different natural resource regions. The project entailed the administration of a detailed field-level survey to farmers in 12 watersheds in the Nation to gather data on agricultural practices, input use, and natural resource characteristics associated with farming activities. The data were analyzed by the Economic Research Service using a consistent methodological approach with the full set of data to study the constraints associated with the adoption of micronutrients, N-testing, split nitrogen applications, green manure, biological pest controls, pest-resistant varieties, crop rotations, pheromones, scouting, conservation tillage, contour farming, strip cropping, grassed waterways, and irrigation. In addition to the combined-areas analyses, selected areas were chosen for analysis to illustrate the difference in results between aggregate and area-specific models. The unique sample design for the survey was used to explore the importance of field-level natural resource data for evaluating adoption at both the aggregate and watershed levels. Further analyses of the data illustrated how the adoption of specific management practices affects chemical use and crop yields.

Keywords: Technology adoption, conservation

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Summary

The Area Studies Project was designed to characterize the extent of adoption of nutrient, pest, soil, and water management practices and to assess the factors that affect adoption for a wide range of management strategies across a range of natural resource regions. The project entailed the administration of a detailed field-level survey to farmers in 12 watersheds in the United States to gather data on agricultural practices, input use, and natural resource characteristics associated with farming activities. The data were analyzed by the Economic Research Service using a consistent methodological approach with the full set of data to study the constraints associated with the adoption of selected farming practices that may reduce environmental damages. In addition to the combined-areas analyses, selected areas were chosen for analysis to illustrate the difference in results between aggregate and area-specific models. The unique sample design for the survey was used to explore the importance of field-level natural resource data for evaluating adoption at both the aggregate and watershed levels.

The econometric analyses focused on the adoption of technologies and practices within four key management categories: nutrients, pests, soil, and water. The technologies compared were micronutrients, N-testing, split nitrogen applications, green manure, biological pest controls, pest-resistant varieties, crop rotations, pheremones, scouting, conservation tillage, contour farming, strip cropping, grassed waterways, and irrigation. Further analyses of the data illustrated how the adoption of specific management practices affects chemical use and crop yields.

There were several key findings.

- An operator's education had a significantly positive effect on his or her adoption of information-intensive technologies, such as the use of biological pest control or nitrogen testing. The increasing complexity of emerging technologies is a factor that needs to be considered by agencies or technology providers when targeting potential adopters. Technical assistance, demonstration, or consulting services may be necessary to promote adoption of certain preferred practices.
- Ownership of the surveyed field had less of an impact on practice adoption than we initially had expected—probably because most of the practices included in this study were not structural.
- The combined-area models represent the aggregation across very distinct watersheds. From a policy perspective, these results can be misleading. The unified modeling approach used shows how important information can be "lost" in the process of aggregation. Adoption incentives developed to address factors identified in the aggregate model may be appropriate for only one area and counterproductive for all others. While this "averaging problem" exists for all policies to some extent, the comparison of the combined-area and single-area models presented here illustrates the magnitude of the differences between the Area Studies regions.
- With respect to the effect of technology adoption on chemical use and yields, we found that, in general, the use of new technologies resulted in little reduction in chemical loadings and no yield decreases.

Adoption of Agricultural Production Practices

Lessons Learned from the U.S. Department of Agriculture Area Studies Project

Margriet Caswell, Keith Fuglie, Cassandra Ingram, Sharon Jans, and Catherine Kascak

1. Introduction

The U.S. agricultural sector provides an abundant and affordable supply of food and fiber. In some locations, however, farming activities are believed to have contributed to the degrading of ground and surface waters. Concern about agriculture-induced water quality problems grew during the 1980s, and several major efforts were undertaken to determine the extent of the problems, potential changes in farming practices that would avoid or mitigate such damages, and policies to effect such changes. This document reports on one of those efforts: The U.S. Department of Agriculture (USDA) Area Studies Project. This project entailed the administration of a detailed field-level survey to farmers in 12 watersheds in the United States to gather data on agricultural practices, input use, and natural resource characteristics associated with farming activities.

The objectives of this report were to use a consistent methodological approach with the full set of data to study the constraints associated with the adoption of selected farming practices that may reduce environmental damages, and to assess how adoption of those practices affected yields and chemical use. In addition, the unique sample design for the survey was used to explore the importance of field-level natural resource data for evaluating adoption at both the aggregate and watershed levels.

The development of the Area Studies Project is described briefly below. The next chapter presents the characteristics of the survey instrument and summarizes the data to show the variety of agricultural land uses, farm sizes, and resource characteristics represented by the survey. Several published studies are described that were based on the use of subsets of the Area Studies survey data. The unified econometric framework that was used to analyze the aggregate data set encompassing 10 areas,[1] and the core set of variables used for each analysis are also presented in chapter 2.

Chapters 3 through 6 present the econometric analyses of the adoption of technologies and practices within four key management categories: nutrients, pests, soil, and water. Each chapter describes survey data relevant for the category and then presents the results of the analyses of the adoption of management practices for the combined area. We used the same unified econometric framework and set of core variables described in chapter 2 for each analysis. In addition to the com-

[1] Data were not sufficient in two of the 12 study areas to provide statistically reliable estimates.

bined-areas analyses, selected areas were chosen for analysis to illustrate the difference in results between aggregate and area-specific models. The symmetry imposed on these chapters is intended to help readers focus on the practices of interest to them and to facilitate using this report to reference individual studies. For example, a reader primarily interested in pest management practices need read only chapters 1, 2, and 4. Chapter 7 describes further analyses of how adoption of specific management practices affects chemical use and crop yields. The final chapter summarizes the results of the comprehensive analysis of the Area Studies survey data and presents the strengths and weaknesses of using a field-level, watershed-based survey approach.

Background of Area Studies Project

In 1989, the President's Water Quality Initiative was started in response to public concern about agricultural chemicals in groundwater. Sediment and chemical loadings can damage environmental quality and human health. Because of the nonpoint nature of the pollution problem, it is hard to trace cause and effect. As Antle and Capalbo (1991) pointed out, "chemical use in agriculture has, over the last 50 years, been the good, the bad, and the uncertain." Studies have since shown that nutrients and sediments from agriculture are the leading source of impairment of U.S. rivers, streams, and lakes (U.S. EPA, 1995, 1998). Ribaudo (1997) presents a comprehensive summary of current water quality issues. Many of the management practices developed to reduce agricultural nonpoint source pollution were believed to be inexpensive to implement and, once implemented, would raise farmers' profits (U.S. Congress, OTA, 1995). These pollution-reducing practices were not being adopted at a rapid rate, however.

The primary objectives of the multi-agency Water Quality Initiative were to: (1) determine the nature of the relationship between agricultural activities and ground water quality, and (2) develop and induce adoption of technically and economically effective agro-chemical management and agricultural production strategies to protect ground water quality. The program was designed with the intent of meeting the objectives without burdensome regulations and without any loss of agricultural productivity and profitability (USDA, 1989). USDA developed programs of research, education, technical assistance, cost sharing, data collection, and analysis. The Economic Research Service (ERS) was given the lead responsibility and funding to build a database on agro-chemical use and associated farm practices. The three primary data efforts were: (1) the Cropping Practices Survey, which provided benchmark measurements and monitored changes of chemicals applied and cropping practices by State for six major field crops for 1990-95; (2) the Vegetable and the Fruit and Nut Chemical Use Surveys, which obtained whole farm, input use, and practice data for major specialty crops; and (3) the Area Studies Survey, which was designed to provide a link between natural resource characteristics, farm production practices, and water quality at a local level.

The Area Studies Project was based on the growing body of work showing the need to link economic models of agricultural production with models of the physical environment. Site characteristics will influence the choice of many production practices and will determine the environmental consequences of that choice (Opaluch and Segerson, 1991; Antle and Capalbo, 1991; Just and Antle, 1990). For example, soil permeability may affect a producer's choice of irrigation system and fertilizer application method. The permeability of the soil will also determine the speed and distance chemical residuals will be transported and the likelihood of their reaching an environmentally sensitive resource. When the effectiveness of practices is correlated with natural resource assets used on the farm, the spatial pattern of practice use will be determined by the distribution of those physical characteristics (Caswell, 1989, 1991). The distribution of physical characteristics will also determine the relative vulnerability of natural resources to agricultural nonpoint pollution (Shoemaker, Ervin, and Caswell, 1993). Early work on identifying groundwater resources that were potentially vulnerable to agricultural chemical degradation was published in Kellogg et al. (1992).

The two fundamental categories of site characteristics are (1) those that have impacts on a grower's choice of production practices and (2) those that will determine the impact of the production choices on environmental quality. These are not mutually exclusive sets of characteristics. For example, the organic content of the soil at a site may be a factor in a farmer's choice of tillage practice and the irrigation system that is used. The organic content will also be a factor in erosion and deep percolation of chemicals that can be affected by tillage and irrigation choices. Each site is associated with a combination of characteristics in the production-impact and environmental-impact categories.

Policy changes that affect practice adoption will alter the spatial pattern of environmental effects, so information is needed on management practices and the

environmental attributes of the land in production (Antle et al., 1995). Heterogeneous land and climate conditions will determine both agricultural production and environmental impacts of policies (Just and Antle, 1990). Wu and Segerson (1995) have shown that if one uses aggregate data and ignores site characteristics in analyzing the impacts of agricultural activities on water quality, one's conclusions may be subject to five potential sources of bias. These sources can be categorized in two types: "(1) Those relating to incorrectly estimating pollution per acre, and (2) those relating to incorrectly estimating the number of polluting acres" (Wu and Segerson, 1995).

The Area Studies survey was developed to test the hypothesis that differences in productivity caused by physical characteristics of farmland will determine the distribution of adoption behavior for some agricultural practices. The production-impact component of site characteristics can be analyzed with economic models. Evaluation of the environmental-impact factors requires physical modeling of the fate and transport of residuals that result from the choices of practices and technologies. The amount of information needed to construct a fully integrated economic and physical model can be daunting, however, even for a small geographic region. Much of the early discussions about developing the Area Studies Project centered on identifying the minimum data needs to estimate the integrated model parameters.

The Area Studies Project was a collaborative effort between USDA agencies (Economic Research Service (ERS), National Agricultural Statistics Service (NASS), and the Natural Resources Conservation Service (NRCS, formerly Soil Conservation Service, SCS)). In addition, there was extensive interaction with the U.S. Geological Survey (USGS) and the U.S. Environmental Protection Agency (EPA).[2] The link between the enumerated survey data and the natural resource base came from the sampling frame, which was based on the NRCS Natural Resource Inventory (NRI) sites. Each observation was identified with a sampled NRI point that provided the physical data that represented the farm operator's resources. Many of the site's production-impact and environmental-impact characteristics are included in the NRI data base and its links.

Two pilot projects were planned to precede the Area Studies Project to test the feasibility of linking agricultural production and potential water quality effects: (1) The Cotton Water Quality Study, and (2) the Delmarva Area Study.[3] The 1990 Cotton Water Quality pilot survey was designed to supplement the Cropping Practices Survey with information on soil resources associated with each surveyed field. The project was meant to provide sufficient information to assess the scope of cotton production by land characteristics most vulnerable to groundwater contamination. The data gathered included soil loss potential, slope, soil texture, proximity of field to water body, agricultural practices used, fertilizer, insecticide, fungicide, defoliant, and growth-regulator use rates.[4] Results from the Cotton Water Quality pilot survey are reported in Crutchfield et al. (1992).

The 1990 Delmarva Area Study data were obtained from a special NASS pilot survey that was designed to interface with an ongoing groundwater study by USGS in the region.[5] The watershed is heavily agricultural, and there is a strong demand for high-quality water resources. The basic survey instrument design used in the Area Studies Project was tested and modified through the Delmarva effort. The survey originally was designed to gather sufficient data to develop a multi-output/input production function to capture the output/input substitution possibilities associated with natural resource assets. This information then would be used within a policy simulation model for each selected watershed. Data needs were prioritized after it became clear that the survey instrument as initially proposed was both long and complex. The highest priority information was crop-specific data on chemical use and practices. The second highest priority need was for economic information related primarily to crop production. Lower priorities were assigned for details about government commodity program participation, off-farm income, and livestock waste disposal. All priorities were included in the Delmarva pilot survey, but it was found that data from many of the economic questions were not statistically reliable.

[2] Bill Wilbur (USGS) and Peter Kuch (EPA) worked closely with ERS staff throughout the Area Studies Project development.

[3] A Florida Area Study pilot was also planned in collaboration with the University of Florida, but funding was insufficient to field three special surveys.

[4] Unfortunately, herbicide use rate data were not gathered due to problems in scheduling interviews.

[5] The Delmarva Peninsula lies between the Chesapeake and Delaware Bays and is so named because it encompasses areas governed by Delaware, Maryland, and Virginia.

In 1991, the Delmarva Area Study pilot project experience and other elements of the ERS Water Quality research program were presented to an external review team made up of university economists.[6] Input from this group was used to make mid-course corrections in program design, particularly with respect to the Area Studies survey development.

It had been envisioned initially that the number of sites surveyed through the Area Studies data collection program would be sufficient to provide the coverage needed to make a national assessment of the extent of agriculture's role in water quality problems. The review team strongly urged that the intensity of sampling at the watershed level not be compromised by attempts to broaden the number of sites surveyed. They advised that the Area Studies Project should focus on understanding economic behavior in relation to natural resource conditions. A criterion for site selection could be the inclusion of representative conditions that characterize U.S. agriculture, but not to claim that it was a national sample. The individual investigations of watersheds and comparisons between them were thought to be the most valuable uses of the survey design that sampled within "environmentally relevant," rather than political, boundaries. These boundaries would correspond to those used by USGS for sampling and assessing water quality conditions. The Cropping Practices Survey and other ERS/NASS surveys could be used for national, State, or regional reporting of crop production or technology use. The Area Studies Project would report information at the watershed level only and primarily be used for research into the link between the adoption of agricultural practices and the natural resource base.

Theory of Adoption Behavior

There is an extensive body of literature on the economic theory of technology adoption. We will review only a small portion of that work. The understanding of the driving forces of adoption is important for the development of pollution-reducing technologies because the effectiveness of the technology will depend on where and when it is used (Stoneman and David, 1986). For many years, there were separate adoption theories in education, sociology, anthropology, medicine, rural sociology, marketing, and industry. Much of it was based on "contagion" theory, which associated the probability of adoption with the proximity of a prior adopter. Griliches (1957), in his pathbreaking work on hybrid corn, showed that profitability was the largest determinant of adoption. Rogers (1983) agreed that the attributes of the technology were important, but that profitability was only one component. He stated that the "five attributes of innovations are (1) relative advantage, (2) compatibility, (3) complexity, (4) trialability, and (5) observability" (Rogers, 1983, p. 211). Profitability in its narrowest sense is only a factor within the first category. However, the other categories can all represent "costs" to a potential adopter because they encompass new information and adjustments that must be made.

The adoption of technology for natural resource management and conservation, such as soil conservation, integrated pest management, soil nutrient testing, and irrigation management, are considered apart from the use of conventional inputs such as agricultural fertilizers and chemicals. While decisions on the amount of conventional inputs to apply are made on a seasonal or annual basis, the adoption of new technology represents a significant shift in a farmer's production strategy. The decision to adopt new technology is analogous to an investment decision. The decision may involve substantial initial fixed costs, while the benefits accrue over time. The initial costs may include the purchase of new equipment and of learning the best techniques for managing the technology on the farm. A producer may perceive the nonmonetary costs of change to be very high.

An individual's assessment of the new technology is subjective and may change over time as a farmer learns more about the technology from neighbors who have already adopted it, the extension service, or the media. When a technology first becomes available, uncertainty about its performance under local conditions is often high. Significant adaptation of the technology may be necessary before it performs well in the local production environment. Over time, as some farmers in an area adopt and gain experience with the new technology, the uncertainty and cost of adoption fall. Some farmers may fail to adopt the technology altogether if they determine that it simply does not perform well under their resource conditions, or if the size or type of their farm operation is not suited to the technology in question (Griliches, 1957).

[6] Members of the external review team were: William Boggess, Susan Capalbo, Otto Doering, Richard Howitt, Tim Phipps, Tony Prato, and Kathleen Segerson. The team met with ERS staff at Airlie House in Virginia, January 22-23, 1991. Written review comments were submitted in March 1991.

A new technology or innovation will change the marginal rate of substitution between inputs in a production process. Some changes may be perceived as large by a potential adopter. Early studies of adoption were based on the assumption that people were resistant to change and that resistance had to be overcome (Nowak, 1984). There is a distinct difference, however, between a producer who is unable to adopt versus one who is unwilling to adopt. Nowak (1992) summarized these two types of barriers to adoption:

Inability to adopt: (1) Information lacking or scarce; (2) Costs of obtaining information too high; (3) Complexity of the system too great; (4) Too expensive; (5) Labor requirements excessive; (6) Planning horizon too short (benefits too far in the future); (7) Limited availability and accessibility of supporting resources; (8) Inadequate managerial skill; and (9) Little or no control over the adoption decision.

Unwillingness to adopt: (1) Information conflicts or inconsistency; (2) Poor applicability and relevance of information; (3) Conflicts between current production goals and the new technology; (4) Ignorance on the part of the farmer or promoter of the technology; (5) Inappropriate for the physical setting; (6) Increased risk of negative outcomes; and (7) Belief in traditional practices.

Many of the distinctions made between inability and unwillingness to adopt are based on relative judgments (i.e., too high, too short, inadequate) and would be difficult to test empirically. Another way to differentiate nonadopters is to characterize them as (1) those for whom adoption would not be more profitable than continuing with current practices, and (2) those for whom adoption would be more profitable but who choose not to switch technologies due to other barriers. Policies designed to encourage adoption would need to be targeted differently for these two groups.

Many of the conservation or chemical-reducing technologies included in the Area Studies analysis can be classed as "preventive innovations" in that they facilitate the adopter's avoiding some unwanted future event such as groundwater contamination or loss of productive soils. As Rogers (1983) points out, preventive innovations have a low rate of adoption because it is hard to demonstrate the advantages of adoption since those benefits occur only at some future, unknown time. Pample and van Es (1977) distinguished between practices designed to protect natural resources and those designed primarily to increase farm profits. They conclude that the "means and goals of the two types of practices appear sufficiently different to possibly result in different adoption behaviors" (p. 58).

The current economic theory of adoption is based on the assumption that the potential adopter makes a choice based on the maximization of expected utility subject to prices, policies, personal characteristics, and natural resource assets. A discrete choice of technology is made that leads to a level of input use and profit. If the benefits associated with the use of a conservation technology accrue primarily beyond the farm, producers would not be expected to include those benefits in their decision to adopt the technology. Many of the recommended practices are designed to reduce off-site environmental impacts rather than to increase on-site productivity. The total benefits of switching to these technologies may outweigh the costs by a large margin, but if those gains are not realized by the farmer who bears the costs, the voluntary adoption of preferred technologies may not occur.

Since neither farms nor farmers are identical, there will be differences in whether a particular technology is adopted and when. Farmers will differ in their ability to understand and adapt to innovative methods, and in the quality of the land they control. The farmer is aware of these factors and uses that knowledge to assess the expected gain of adoption. The distribution of the underlying heterogeneous factors will determine the pattern of practice adoption. When one of the heterogeneous factors is associated with natural resource characteristics, the adoption pattern can be defined spatially.

The effectiveness of policies designed to improve water quality or other environmental assets through promoting the adoption of conservation technologies and management strategies will depend on an understanding of how farmers choose their production practices. The Area Studies Project was designed to characterize the extent of adoption of nutrient, pest, soil, and water management practices and to assess the factors that affect adoption for a wide range of management strategies across diverse natural resource regions.

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2. Data and Modeling Framework

In this chapter, we briefly describe the areas included within the survey sample and the survey instrument. We then summarize the Area Studies survey data with respect to agricultural land use, farm size, and general natural resource characteristics. Following the overview of the data, we present some empirical studies that used the Area Studies survey data. The results of these efforts offered insights on the development of a comprehensive analysis of the Area Studies survey data. We then present the unified modeling framework that was used to analyze selected nutrient, pest, soil, and water management practices. The analyses of the adoption of these practices are described in later chapters. This chapter concludes with a presentation of the core set of variables that are used in each analysis.

Summary of Area Studies Survey Data

The Area Studies survey data were collected for the years 1991-93 in 12 U.S. watersheds. The areas chosen were part of the USGS National Water Quality Assessment Program (NAWQA), which was designed to represent a large part of the Nation's surface- and ground-water resources and to provide scientific understanding of the primary natural and human factors affecting the quality of these resources. Data were collected at about 10,000 sample fields within 13 of the 60 NAWQA Study Units. The 13 areas selected had a high proportion of cropland relative to other NAWQA sites at which there was extensive water quality monitoring. Each area is defined by watershed boundaries that do not necessarily correspond with State or county borders. In some of the watersheds, the survey was administered to a subregion of the entire area.

The Area Studies survey instrument was designed to collect detailed information on the use of cropping systems, agricultural production technologies, and chemicals at both the field and whole-farm level. A personal interview questionnaire was administered to farm operators by the National Agricultural Statistics Service (NASS). The survey sample was chosen to correspond with sample points from the Natural Resources Conservation Service (NRCS) 1992 National Resource Inventory (NRI). Generally, the sample was designed to obtain about 1,000 sample fields in each area. Larger areas had more samples and smaller areas had fewer samples. Sample fields were selected using a stratified random selection of NRI sample points using information on soil properties and land use from the 1982 and 1987 NRIs (for the 1991 and 1992 samples) and the 1992 NRI (for the 1993 samples). The NRI contains data on the natural resource condition of the United States and was conducted in 5-year intervals since 1982. The 775,000 NRI points in the national sample are mapped into 16,167 polygons consisting of the overlay of county, watershed, and Major Land Resource Area (MLRA) boundaries (Kellogg et al., 1992). Each point represents 5,000-7,000 acres (expansion factor). The NRI includes information about soil, water, and related resources on U.S. farms and nonfederal forests and grazing lands. The NRI points establish a link between agricultural production activities collected from the Area Studies survey and resource characteristics compiled from the NRCS Soil Interpretations Records database, which includes information on land use and cover, cropping history, soil erosion levels, and other soil characteristics.

Description of Areas Surveyed

The areas surveyed in 1991 were the Central Nebraska River Basins, White River Basin in Indiana, Lower Susquehanna River Basin in Pennsylvania, and Mid-Columbia River Basin in Washington. The areas selected for the 1992 Area Studies survey were the Albemarle-Pamlico Drainage in Virginia, Southern Georgia Coastal Plain, Illinois/Iowa Basins, and Upper Snake River Basin in Idaho. The 1993 regions selected for the survey were the Southern High Plains in Texas, the Mississippi Embayment, Southern Arizona, and the San Joaquin-Tulare Basins in California. Unfortunately, the survey efforts in Arizona and California did not result in enough usable observations to accurately characterize the areas. Therefore, these areas were not included in the following analyses. Figure 2.1 shows the 10 Area Studies survey sites used for analysis. A short geographic description of each of these 10 areas is given below. A comparison of some of the general characteristics of the agricultural areas is included as well. Geographic and area-specific information was presented in a series of NAWQA Fact Sheets (U.S. Geological Survey, 1993 through 1997).

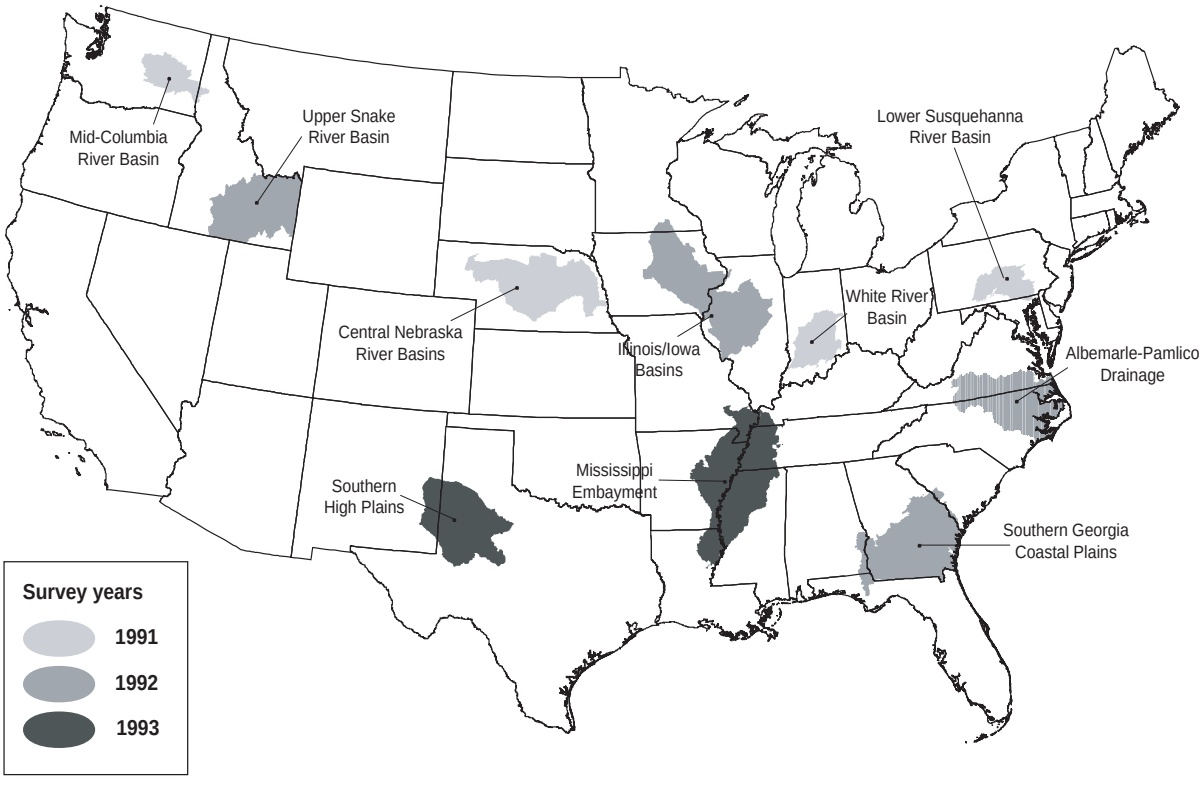
Central Nebraska River Basins The Central Nebraska River Basins area is approximately 30,000 square miles and includes the Platte River and its tributaries between the confluences of the North and South Platte Rivers in western Nebraska and downstream to

the Missouri River at the eastern boundary. Other major tributary systems in the area include the Loup and Elkhorn River basins. The Platte River is located within the Central Flyway and provides critical habitat for wildlife and migratory birds. The western three-fourths of the area is in the Great Plains physiographic province, characterized by gently rolling grasslands. The eastern one-fourth of the area lies in the more humid Central Lowlands physiographic province, which typically consists of loess-covered hills with native tall grasses. The Platte and Loup River systems and the underlying High Plains aquifer are critical resources in the area because irrigated agriculture is the dominant land use, with 41 percent of the 19.1 million agricultural acres used for crop production and 59 percent used as non-crop land, mainly pasture. Fifty-five counties in Nebraska were at least partially included within the survey area.

White River Basin The White River Basin is part of the Mississippi River system and drains 11,349 square miles of central and southern Indiana. There are two major subbasins in the river system: the eastern part of the basin is drained by the East Fork White River, and the western part of the basin is drained by the White River. At least three glacial episodes covering more than 60 percent of the basin created three distinctly different physiographic provinces. The northern half of the basin, Tipton Till plain, is a flat to gently undulating depositional plain of the Wisconsin Age. The southwestern part of the basin was glaciated during Illinoian age. The area has been extensively reworked and is composed of mostly sand and gravel deposits of glaciofluvial origin. Bedrock outcroppings in the southern part of the basin are characterized by alternating layers of more and less resistant rocks. Agriculture is the primary land use in the basin, with the northern half more extensively farmed than the southern half. Total agricultural acreage in the area is 19 million and 88 percent is planted in crops, mainly corn and soybeans. Thirty-eight counties in Indiana were at least partially included within the survey area.

Lower Susquehanna River Basin The Susquehanna River drains about 27,000 square miles of New York, Pennsylvania, and Maryland. Seven major tributaries drain about two-thirds of the lower basin. The Susquehanna River itself flows through three consecutive reservoirs and dams in the lower basin before reaching the Chesapeake Bay. Three physiographic provinces are included in the lower basin. The Valley and Ridge is the first physiographic province and is underlain by folded and faulted rocks that form steep mountains and ridges separated by valleys. The second, the Piedmont physiographic province generally has terrain that is gently rolling and hilly. Only a

Figure 2.1
USDA area studies survey sites



small part of the lower basin has the third physiographic province, the Blue Ridge, which is underlain by crystalline rocks. Agriculture is the dominant land use in the study area. Total agricultural acreage is 1.56 million acres, with cropland covering 83 percent of acres. Twenty-two counties in Pennsylvania and three counties in Maryland were at least partially included within the survey area.

Mid-Columbia River Basin The mid-Columbia River basin comprises 19,000 square miles in eastern Washington and western Idaho. It is drained by the Columbia River and its major tributaries, the Snake River, Crab Creek, and the Palouse River. The basin is underlain by massive basalt flows, and sedimentary deposits overlie the basalt over large areas. The west-central part of the basin is characterized by deep canyons and coulees, whereas the southern part is rolling hills. The area is dominated by agricultural activities on irrigated and nonirrigated land. There are 7 million agricultural acres in the area and 49 percent of this acreage is cropland, with wheat being the principal crop. Included within the survey area or partially included were seven counties in Washington and one county in Idaho.

Albemarle-Pamlico Drainage The Albemarle-Pamlico drainage area encompasses about 27,500 square miles of southern Virginia and northeastern North Carolina, and it excludes the open waters of Albemarle and Pamlico Sounds. Slightly more than half of the area is defined by the three physiographic provinces, the Valley and Ridge, Blue Ridge, and Piedmont, while the remainder is in the Coastal Plain. Agriculture is the principal land use in the study area. Total agricultural acreage is 4.58 million acres and cropland is 78 percent, primarily soybeans and corn. Forty counties in North Carolina and 25 counties in Virginia were at least partially included within the survey area.

Southern Georgia Coastal Plain The Southern Georgia Coastal Plain study unit is an area of about 54,000 square miles that mainly includes southern Georgia and small areas of northern Florida, Alabama, and South Carolina. The land surface consists of irregular plains in most of Georgia and northern (panhandle) Florida, and smooth plains in the coastal area of Georgia. The topography, long growing season, and more than 50 inches of rainfall annually, make the area highly suitable for agriculture. Seventy-one percent of the 5.66 million agricultural acres are used for cropland. Seventy-seven counties in Georgia, five counties in Alabama, two counties in Florida, and three counties in South Carolina, were at least partially included within the survey area.

Illinois/Iowa Basins The Illinois/Iowa Basins survey area is a combination of two NAWQA sites, the lower Illinois River basin and the eastern Iowa basins. In total, this area covers 37,460 square miles, extending from central and western Illinois through eastern Iowa and into southern Minnesota. The lower Illinois River basin extends from the Illinois River at Ottawa, IL, to the confluence of the Illinois and Mississippi Rivers at Grafton, IL. The Illinois River is a navigable link between Lake Michigan and the Mississippi River. The major aquifers in this basin are composed of glacial deposits of Quaternary Age and bedrock of Pennsylvanian to Mississippian Age. The eastern Iowa basins can be divided into three major physiographically distinct regions: 1) the Des Moines Lobe is typified by low relief with some ridges and occasional depressions that form lakes, ponds, and swamps, 2) the Iowan surface is characterized by a gently rolling topography with long slopes, low relief, and a mature drainage pattern, 3) the Drift Plain, is steeply rolling terrain with broad, flat drainage divides. In the combined Illinois/Iowa basin, land use is primarily agricultural, with 87 percent of the 19 million acres used for cropland. Corn and soybeans are the major crops in the basin. Forty-six counties in Illinois, 46 counties in Iowa, and 4 counties in Minnesota were at least partially included within the survey area

Upper Snake River Basin The Upper Snake River basin is approximately 35,800 square miles, extending from Yellowstone National Park in northwestern Wyoming to King Hill in south-central Idaho. The relatively flat Snake River is the dominant feature in the study area, and 24 major subbasins are tributaries to the Snake River. The area is divided into two sections. The smaller of the two sections is the upper Snake River basin found mostly in Wyoming. It has three physiographic provinces; the Columbia Plateau, Rocky Mountain, and Basin and Ridge. The larger of the two sections is the eastern Snake River Plain, which is in Idaho and is an extension of the Columbia Plateau province. Located within the area are Yellowstone and Grand Teton National Parks and the National Elk Refuge. Agriculture is important in the area, with 5.7 million acres almost equally divided between cropland (51 percent) and non-cropland (49 percent). The major use of cropland is potatoes and wheat while the major use of non-cropland is range. Included within the survey area were 22 counties in Idaho.

Southern High Plains The Southern High Plains study unit is an area of about 39,590 square miles with 15 percent of the area in eastern New Mexico and the remainder in the Texas Panhandle. The Southern High Plains plateau is underlain by the High Plains (Ogallala) aquifer and contains about 22,000 shallow depressions, termed playas, that accumulate runoff from local watershed areas following heavy rainfalls. The study area is situated in the Central Flyway, a route traversed by millions of waterfowl on their annual migrations. The High Plains of west Texas, with its semiarid climate, mild winters, and the playa habitat, make it the second most important waterfowl wintering region of the Central Flyway, exceeded only by the Texas Gulf Coast. The major land uses in this study area are livestock grazing and agricultural cultivation. Total agricultural acreage is 19 million acres, with non-crop land, mostly rangeland, covering 67 percent of the acres. Cultivated cropland comprises the remaining 33 percent of the agricultural acreage, with cotton as the dominant crop grown. Three counties in New Mexico, and 37 in Texas were at least partially included within the survey area.

Mississippi Embayment The Mississippi Embayment area covers approximately 48,500 square miles and includes parts of Arkansas, Kentucky, Louisiana, Mississippi, Missouri, and Tennessee. The drainage area extends downstream from the confluence of the Mississippi and the Ohio Rivers to just south of Vicksburg, Mississippi. Also included in this area are the drainage basins of several smaller rivers (the Yazoo, the Hatchie-Obion, the St. Francis-Lower White, and the Bayou Bartholomew-Tensas). This area is dominated by agricultural activities. Total agricultural acreage is approximately 21.1 million acres and 79 percent of the acreage is cropland, with soybeans and cotton the major crops. Twenty-three counties in Arkansas, 7 counties in Kentucky, 9 counties in Louisiana, 33 counties in Mississippi, 9 counties in Missouri, and 18 counties in Tennessee were at least partially included within the survey area.

Survey Instrument

In this section, we present a general description of the Area Studies sample design and survey instrument, a detailed discussion of the data used for analysis, and definitions of variables.

Farm operators were selected for participation in the Area Studies survey by using an area-frame sampling method. NRCS provided primary sampling units (PSUs) that encompassed approximately three NRI points. The NRI was based on a stratified random sampling design in which soil, water, and related natural resource data are collected at nearly a million sample sites throughout the United States. Choosing the sample so that it coincides with a subset of NRI points ensures that information on soil properties will be available, and provides a means for statistical aggregation of the agricultural sector based on land use.

The sampled fields were weighted so that they are spatially representative of the watersheds. The sample was chosen to target crop rather than livestock production. Each point in the sample frame was assigned an acreage value equal to the total number of acres in the PSU divided by the number of points in the PSU. Each sample point was assigned a weight consisting of this acreage value multiplied by the inverse of the probability of that point's having been selected. As a result, the sum of the weights provided for each Area Study region is an estimate of the total acres of agricultural land in the universe sampled.

For each questionnaire, a personal interview was conducted with the farm operator to determine cropping practices used during the previous 3 years and general information about the farm operation. Field-level and whole-farm data were collected from farm operators in the Area Studies regions. The Area Studies survey was conducted in the fall after crops were harvested. For many of the questions, however, farmers were asked about the use of cropping practices for the previous 3 years. The number of usable observations from the 1991, 1992 and 1993 surveys totaled 9,863.

The main section of the survey was designed for gathering field-level data. After the field was identified, information was collected about the primary use of the field, field location, and land rental values. Questions then were asked about the number of crop acres planted and harvested, average crop yield, planting date, and tillage practices used on the field. This information was collected for the survey year as well as the two previous years. Farmers also were asked if they participated in government programs and whether they had crop insurance. Finally, some information was compiled on livestock history.

In addition to basic crop and livestock data, farm operators also were asked about their cropping practices, with questions on the farmers' management of nutrients, pests, soil, and water. This section was designed to link the adoption of resource management technologies with chemical use.

To assess their management of nutrients and fertilizer, the farmers were asked about soil testing, sources of fertilizer information, manure applications, the amount and type of fertilizer applied, and acres treated. The fertilizer data include information on the method of fertilizer application, how much fertilizer was applied per acre, and the date fertilizer was applied.

For their pest management strategies and chemical use, farmers were asked about their pest control history, such as weed control methods, and the type, amount, cost of chemicals applied for overall pest control and application date, source of pest management advice, and the methods used to apply chemicals.

For soil and water management practices, data were collected on the types of soil conservation practices used over the past 3 years.

For their water management practices, farmers were asked about the irrigation system used, water source, quantity of water applied, drainage systems, and who advised the operator about when to irrigate.

The objective of the whole-farm portion of the survey was to determine the range of cropping activities for the entire farm and the characteristics of the farm operators. The respondents were asked about the total number of acres operated on the farm as well as farm type, crops planted and harvested, and livestock history. Some financial information was collected, such as labor costs and crop sales. The farm operators were also asked their tenure status, age, education, years of experience, and days worked off the farm.

The final section of the survey was designed to collect information on why the respondent did or did not adopt specific farm management practices.[1] This was an experimental section that was left with the farm operator who was requested to mail the form when complete. In the farm management section, there was an attempt to collect data on the costs (before cost-sharing) associated with the use of specific resource management practices. Farmers also were asked whether or not the practice was cost-shared, the effect of the practice on profits, and information sources consulted about the technology. The response rate was low for this section of the survey since it was not part of the personal interview. In addition, the questions were changed significantly from year to year to improve the instrument, and were not mutually consistent. Therefore, these data were not used in the analysis presented in this report.

In the following sections of this chapter, we provide some descriptive statistics for each Area Studies region. The descriptions focus on agricultural land use, average farm size, and natural resource characteristics of the field. These characteristics, which are important factors in the adoption analysis, vary widely across the sampled areas. The NRI connection to the Area Studies sample provided the natural resource data that was used to calculate the potential of soil to erode and leach.

Agricultural Land Use There are many variations among the areas both in geographic characteristics and in land use. Agriculture was the primary land use for each of the Area Study regions. Total agricultural acreage for each area, as well as acres in cropland and non-cropland, are presented in table 2.1. The major crops cultivated in the surveyed areas were corn, cotton, alfalfa and hay, soybeans, wheat, and others.[2] The Illinois/Iowa Basin had the largest area devoted to corn production, slightly greater than 9 million acres, followed by Central Nebraska Basins with 3.9 million acres. The Mississippi Embayment and Illinois/Iowa Basin had the largest area planted with soybeans, 7.4 and 6.4 million acres, respectively. In addition, the Mississippi Embayment had the largest area in cotton, 4.6 million acres, followed by the Southern High Plains at almost 3.2 million acres. Non-cropland includes pasture, the Conservation Reserve Program (CRP), rangeland, fallow, idle, set-aside, woodland, and wetlands. Only two areas, the Southern High Plains and Central Nebraska Basins, had more than half of their total agricultural acreage in non-cropland, 67 and 59 percent, respectively.

Farm Size Farm size by agricultural area varied distinctly across the different regions (fig. 2.2). In general, there was a larger proportion of small farms in the eastern survey areas, and more large farms in the western areas. Over 35 percent of farmers in the Albemarle-Pamlico Drainage, Southern Georgia Coastal Plain, and the Illinois/Iowa, Susquehanna, and

[1] The practices covered in the farm management section included conservation tillage, stripcropping, contour farming, waste storage, pesticide handling, pest management, legume crediting, manure and nutrient testing, split applications of nitrogen, drip irrigation, and soil moisture testing.

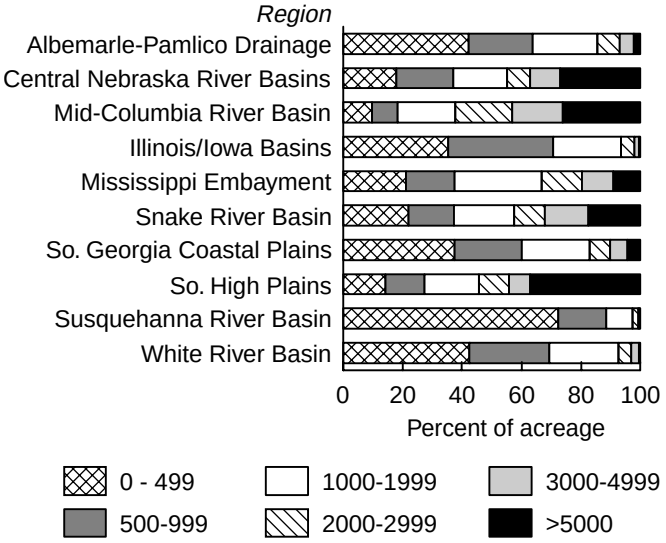
[2] Some crops within the "other crops" category may have large acreage in a specific area but do not comprise a significant portion of the total acreage. For example, potatoes are the main crop in the Upper Snake River Basin, so almost 42 percent of the cropland in this area is designated as "other crops."

Table 2.1—Agricultural uses in Area Study regions (1,000 acres)

Region	Cropland							Not cropland						Total agricultural acres
	Corn	Cotton	Alfalfa and hay	Soy-beans	Wheat	Other crops	Total crop acres	Pasture	CRP	Range	Fallow, idle & set-aside	Wood- & wetland nonag	Total noncrop acres	
Albemarle-Pamlico Drainage	864	317	288	944	441	740	3593	671	86	0	212	22	991	4584
Central Nebraska River Basins	3920	0	1550	1654	160	486	7770	10146	328	661	221	15	11371	19140
Mid-Columbia River Basin	121	0	260	0	2239	818	3438	915	694	686	1252	43	3589	7027
Illinois/Iowa Basins	9019	0	637	6407	180	321	16565	1260	791	0	350	92	2492	19058
Mississippi Embayment	1111	4619	388	7395	1137	2012	16661	2136	1036	0	1297	43	4512	21173
Upper Snake River Basin	104	0	687	0	903	1214	2908	810	641	1078	273	0	2802	5711
So. Georgia Coastal Plains	877	519	152	608	313	1562	4030	683	436	0	467	47	1633	5662
So. High Plains	426	3192	325	0	1158	1103	6205	376	2087	9404	1011	3	12882	19086
Lower Susquehanna River Basin	547	0	416	92	66	172	1293	245	5	0	22	0	272	1564
White River Basin	1686	0	166	1331	152	69	3403	307	36	0	90	14	447	3850

* May not add due to rounding.

Figure 2.2
Farm size by region



White River Basins cultivated less than 500 acres. The smallest farms were found in the Susquehanna River Basin where 72 percent of farmers operated less than 500 acres. In contrast, the Southern High Plains, Central Nebraska Basins, and mid-Columbia River Basin had more than 25 percent of farms with crop acreage greater than 5,000 acres. Regional differences in farm size often reflect the farming practices in each area. For example, farms in the Southern High Plains had large numbers of acres devoted to rangeland, whereas the Susquehanna River Basin consisted mostly of small dairy farms.

Natural Resource Characteristics The Area Studies Survey project established a link between farm production activities and the natural resource attributes of a water basin. Soil is one of the most important natural resource assets and is essential for agricultural production. Inherent soil quality is an important factor that defines how a technology will perform in an area. Soil attributes, such as erosion and leaching potential, may influence a farmer's choice of agricultural practices and represent the production-impact characteristics used in the analysis. Measures of soil quality can also be used to analyze the impacts of farming practices on the environment, but modeling the fate and transport of residuals is beyond the scope of this study. The Kellogg et al. (1992) study showed how the environmental impact characteristics of an area can be used to determine potential vulnerability of a region's water resources to agricultural chemical pollution.

Soil Erosion. Land was designated as highly erodible using the NRCS criterion that the potential soil loss due to sheet and rill or wind erosion divided by a soil loss tolerance factor is greater than or equal to 8.[3] Figure 2.3 shows the distribution of highly erodible land (HEL) by Area Studies survey site. Five of the 10 survey sites—Albemarle-Pamlico, Iowa/Illinois Basins, Mississippi Embayment, Southern Georgia Coastal Plain, and White River Basin—had less than 25 percent of agricultural land classified as HEL. Alternatively, more than half of the agricultural land in the Central Nebraska Basins, the Southern High Plains, and the Susquehanna River Basin was classified as HEL. The Southern High Plains has the largest percentage of agricultural land considered HEL, about 73 percent. Most of the HEL in this area was subject to wind erosion rather than sheet and rill erosion.

Soil Leaching Potential. One measure of environmental vulnerability is the inherent potential of soil to leach chemicals into groundwater. The soil leaching potential (SLP) variable used in the Area Studies analysis is based on an index developed by Weber and Warren (1993). The soil characteristics used to construct the SLP index are soil texture, pH, and organic matter. These soil attributes can be obtained from the NRCS Soils Interpretations Records database. Weber and Warren used a weighting scheme to combine these factors into an SLP index that measures the inherent potential of soils to leach, and does not include the properties of pesticides. For the descriptive analyses of the areas, the categories were designated as High, Moderate, and Low.

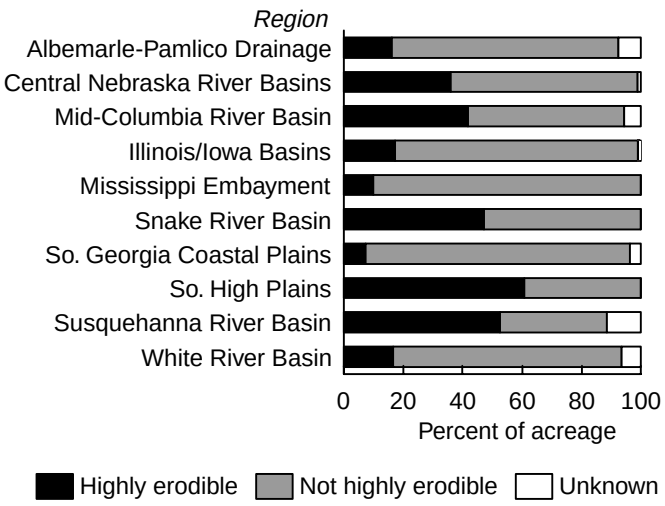
Figure 2.4 illustrates the distribution of leachable soils in the Area Studies regions. As expected, soil leaching potential varies regionally. Of all the areas, the Susquehanna and Illinois/Iowa River Basins had the least amount of agricultural land with high SLP, about 4 and 7 percent, respectively. Areas that had over 50 percent of agricultural land on soils with high SLP include the Snake River Basin with 69 percent, mid-Columbia River Basin with 55 percent, Southern High Plains with 82 percent, and the Southern Georgia Coastal Plain with 87 percent.

Past Analyses of Area Studies Survey Data

Originally it was expected that a team of university and agency researchers would be assigned to each area and be required to use a consistent approach to address a core set of policy questions. Insufficient funds were

[3] A more complete description of soil loss measurement and inherent erodibility is provided later in this chapter.

Figure 2.3
Highly erodible cropland by region



available, however, to facilitate such a level of coordination. Therefore, the Area Studies data were made available to researchers through special agreements.[4] The following discussion reports on some of the dissertations and published work that were based on research using the Area Studies data.

Most of the studies used the 1991 set of data and focused on a single area and crop. Unexpected delays in data availability made multiple-year analyses difficult. In addition, inconsistencies in questions and data definitions across survey years caused problems for researchers. When the comprehensive ERS analysis was initiated, many staff hours had to be committed to forming a single, integrated data set. Despite the difficulties, several researchers completed studies that gave important insights into the strengths and weaknesses of the survey effort and the methods to analyze the data.

The Area Studies survey analyses can be categorized as those using normative models and those using positive models. The normative empirical work is based on computing profits, input use, and other factors using assumed parameters for production functions, costs, and efficiencies. Positive models identify factors that actually affect adoption and assess the importance of those factors on the adoption decisions.

Normative Models

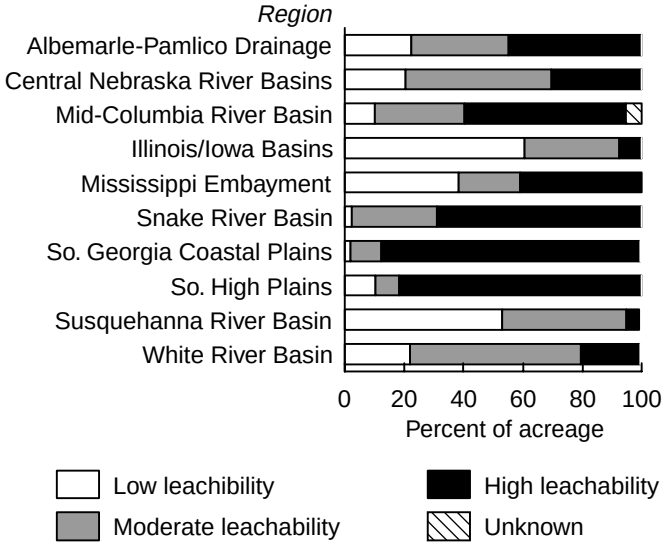
Several researchers used linear programming techniques to estimate the effects of policies that limit input use or the use of certain production management practices. For these studies, supplementary data were necessary to construct crop enterprise budgets and estimate revenues. Bosch and Carpentier (1995) focused on dairy farms in the Lower Susquehanna Basin to assess policies to limit nitrogen runoff. Each sample data point was modeled as an individual farm. The shadow prices on the levels of nitrogen runoff approximate marginal costs. The studies compared the costs of controlling nonpoint sources of pollution between uniform and targeted performance standards. Results from this work show that a targeted performance standard can effectively reduce environmental loadings with a relatively small impact on aggregate farm income (Bosch and Carpentier, 1995; Carpentier and Bosch, 1996, 1997; Carpentier, 1996; and Carpentier, Bosch, and Batie, 1998). In the Susquehanna analysis, they found that "46 out of 237 farms contribute 89 percent of the required reduction in nitrogen delivery for the watershed [50 percent of the reduction could have been achieved by 7 farms]" (Carpentier and Bosch, 1997).

Linear programming models were also used to analyze the White River Basin area in Indiana. Pfeifer et al. (1995) developed nine model farms using the Area Studies survey data and the Purdue Crop/Livestock Linear Program. The model was used to assess the impact of an Atrazine herbicide limitation and a restriction on tillage. This work and the study by Rudstrom (1994) show the tradeoffs between herbicide and erosion restrictions. Mechanical control of weeds with tillage is a substitute for chemical weed control. Restrictions on one or both options will change the mix of practices.

Huang et al. (1995) estimated the impact of changes in agricultural commodity program set-aside requirements on the relative acreage in continuous corn and corn in rotations in the Central Nebraska Basin area. The Area Studies survey data were used to determine crop yield and chemical use associated with each crop production practice and land type. Separate crop budgets were developed for each combination. A linear programming model was used to maximize returns from crop production and government program payments. Quantities of herbicide use and residual nitrogen were estimated for each set-aside scenario. Huang et al. concluded that planting flexibility options have different impacts on crop production in each subwater-

[4] These agreements were designed to protect the anonymity of all survey respondents. Requests for access to the data should be made to the Data Coordinator of the Resource Economics Division in ERS.

Figure 2.4
Soil leaching potential by region



shed due to differences in resource characteristics associated with each area.

Huang, Shank, and Hewitt (1998) analyzed the fertilizer timing decisions of corn farmers in the White River Basin of Indiana. They developed a quadratic production function to estimate the relationship between the adoption of split application of fertilizer and crop yield. They found that split application (in spring and during the growing season) would be optimal only if a risk-neutral farmer perceived a less than 30 percent chance that he or she would be unable to apply nitrogen during the growing season.

Bosch, Kascak, and Heimlich (1996) used the Area Studies survey data to assess the importance of aggregation bias on policy analysis. They developed a representative farm using average data from the Virginia portion of the Albemarle-Pamlico watershed to create an aggregate analysis. Then, they created a spatially disaggregated approach using linear programming estimation by running the farm models individually, as was done in the Carpentier and Bosch work cited above. The two approaches were used to compare the impacts of a nitrogen reduction policy. They conclude that "with respect to agricultural nonpoint pollution, failure to account for diverse farm characteristics may lead to biased estimates of pollution, production, and income" (Bosch, Kascak, and Heimlich, 1996). This conclusion supports that by Wu and Segerson (1995) who found that basing pollution-reduction policies on county averages will be sufficient only when production and pollution characteristics are not correlated. Otherwise, there may be large errors in the identification of polluting acreage.

Positive Models

Several empirical models of technology adoption were estimated. Fuglie and Klotz (1995) looked at the adoption of conservation tillage in the Lower Susquehanna Basin. Using a logit model of estimation, they found that large farms were less likely to use conventional tillage methods than mulch or no till. Crop rotations significantly increased the probability of using a no-till system. Fuglie (1999) estimated the factors influencing the adoption of conservation tillage in the Corn Belt and the effect of that adoption on pesticide use. He found no statistically significant differences among tillage systems in the quantities of herbicides or insecticides used. Bosch, Cook, and Fuglie (1995) undertook another empirical adoption study on the factors affecting the adoption of nitrogen testing on corn in the Central Nebraska Basins area. They found that irrigated fields were 42 percent more likely to have nitrogen tests than unirrigated fields.

Mitra (1997) used the Area Studies survey data for the Albemarle-Pamlico watershed to evaluate the effects of farm advisory services on the toxicity of pesticides used on cotton and peanuts. The study found a positive correlation between aggregate toxicity of chemicals and the farmer's age and whether that farmer used the advice from chemical dealers and scouting personnel. More years of farming were associated with a slight decrease in agricultural chemical toxicity on cotton farms (Mitra, 1997).

Wu and Babcock (1998) expanded the work on the adoption of single technologies to simultaneously estimating the choice of soil nitrogen testing, rotation, and conservation tillage for corn farmers in the Central Nebraska Basins area. Since all the choices of production practices are simultaneous to some degree, the choice of the particular practices in this analysis were dictated primarily by data limitations. They found that adoption of conservation tillage was significantly affected by physical characteristics of the site, farmer education, and participation in the Federal commodity program for corn. Adoption of the other practices was also affected by factors representing human capital, production characteristics, agricultural policies, and natural resource characteristics.

Further work by Bosch, Fuglie, and Keim (1994) and Fuglie and Bosch (1995) used the switching-regression (simultaneous equations) approach to assess the impact of soil nitrogen testing on fertilizer use and corn yields

in the Central Nebraska Basins area. The switching-regression model was used to control for sample selection bias that may reflect unobserved factors that differentiate adopters and nonadopters. Results of these studies showed that the benefits of adopting nitrogen-testing technologies were greatest for fields for which there was considerable uncertainty about the quantity of soil nitrogen, such as when crop rotations or manure applications were used.

Several researchers used the experimental mail-in portion of the Area Studies survey. Norton and Phipps (1994) and Norton (1994) used the 1991 survey results in a random utility model to derive indirect utilities that are functions of field-level and socioeconomic characteristics. The hypothesis being tested was that farmers would adopt pollution-reducing technologies without full compensation (i.e., would accept a lower cost-share payment) if the technology was perceived to improve on-farm environmental quality. Unfortunately, the subsidy percentage variable was not significant. The authors state (and we concur) that data limitation associated with that portion of the survey instrument drove the result, and that the hypothesis could not be rejected on the basis of this analysis. USDA fixed cost-share amounts do not represent (except coincidentally) the difference between profits with and without adoption.

Feather and Cooper (1995) and Cooper and Keim (1996) obtained stronger results using the 1992 Area Studies main survey and the experimental follow-on component. They used a bivariate probit with sample selection model and a double-hurdle model to predict farmers' adoption choices as a function of the payment offer. The results of the models show that there is a positive relationship between the offer amount and the probability of adoption. The strength of the influence differs significantly between practices.

One of the most innovative uses of the Area Studies data was the Crutchfield et al. (1995) study of benefits transfer methods. They showed how estimates of willingness-to-pay for groundwater quality can be used to characterize benefits in areas beyond the original study sites. To calculate the total willingness-to-pay for the four 1991 Area Studies sampled watersheds, Crutchfield et al. used the age and education variables from the survey directly. Income, sex, race, and other variables were taken from averages within the sampled counties. The unique feature of the study was the construction of a risk potential index from the natural resource data to link willingness-to-pay for groundwater quality to a qualitative measure of environmental risk. They concluded that "the estimates of the total willingness-to-pay vary widely, but most likely lie between $73 million and $780 million per year" (Crutchfield et al., p. 18, 1995).

Each study presented in this brief survey gave us insights into how to design the comprehensive analysis of the Area Studies survey data. The approaches based on linear programming models required significant input from other data sources. Such models are best suited for the study of an individual area. Therefore, we chose the positive approach and empirically estimated the adoption of selected management practices across all areas using a simple unified modeling framework. Area-specific models are also presented to illustrate the differences between aggregate and regional influences. The following describes the specific modeling framework and variables that were used.

Unified Modeling Framework

Previous studies using the Area Studies data often dealt with a subset of the sample—particular locations, crops, and technologies. As presented above, these research efforts provided key insights into specific areas, but there had been no attempt to analyze the data set in a comprehensive way. This study is an attempt to use a unified framework of analysis to look across all areas and technologies.

The focus of this study is on technologies that help to conserve natural resources by improving the efficiency of chemical or mechanical inputs used in agricultural crop production. Many of these technologies involve using more intensive management methods or information technology in conjunction with chemical inputs. By making more judicious use of conventional inputs, it may be possible to reduce or mitigate potential environmental consequences of agricultural production while at the same time improving farm productivity and profitability. Each of the four major management categories was studied using all areas combined, and then selected areas were assessed to see whether important site-specific factors would be missed by aggregating across areas. In other words, would factors that strongly influenced adoption in individual watersheds be "averaged out" in the combined model and appear to be unimportant? In addition, broad environmental indicators were used to test how well they performed relative to more site-specific factors. A set of core variables was used so that results could be compared between analyses of different management practices. For example, to assess whether the educational level of the operator influenced adoption differ-

ently for specific practices, a common definition of education must be used within comparable models.

The objectives of the econometric analyses presented in chapters 3-6 are to identify the principal constraints to the adoption of resource-conserving technologies in agriculture. In chapter 7, we assess the effect of adoption on chemical input use and crop yield for a set of selected crop, area, and technology case studies. The model takes into account the influence of important environmental and natural resource attributes on the adoption decisions of farmers. These characteristics are meant to capture the *production-impact* factors discussed earlier. Our hypothesis is that these factors affect the location-specific performance of production management practices and therefore have a significant influence on the spatial pattern of adoption. Furthermore, the effect of adoption on input demand and output supply is expected to be dependent on the quality of natural resources (Caswell, Zilberman, and Casterline, 1993; Fuglie and Bosch, 1995).

The econometric model used to examine patterns of technology adoption and resource use is derived from the utility or profit maximization framework described in chapter 1. Formally, we assume that a farmer adopts a new technology only if the utility (benefit) the farmer receives is greater with adoption. We do not observe utility directly for either technology, however, but only the outcome of this calculation. When there is a choice between only two technologies, we designate M_i=1 if the farmer has adopted management technology or practice i and M_i=0 otherwise. In some cases, technology adoption involves a choice among more than two competing systems. For example, farmers choose among several tillage systems, including no-till, other forms of conservation tillage, and conventional tillage systems. The details of the nonlinear estimation procedures that we used are presented in appendix 2-A.[5] We hypothesize the utility or profitability of adoption to be a function of a set of exogenous variables Z, which include factors that affect the performance of the technology on the farm, such as resource characteristics, and factors that influence the unit cost of adoption, such as prices, farm size, and human capital (Rogers, 1983). Management technology adoption can be characterized as:

$$M = Z'\gamma = \varepsilon \qquad (1)$$

where γ is a vector of parameters and ε is an error term that includes measurement error and unobserved factors that affect adoption (Amemiya, 1981). The underlying principle behind equation 1 is that farmers are heterogeneous in their characteristics, and not all of them find it profitable or worthwhile to adopt a new technology at the same time. Estimation of the parameters to equation 1 provides important information on the influence of resource characteristics, farm size, human capital, and other variables on the pattern of technology adoption and the possible constraints to further adoption.

In this study, we used the logit model to estimate models where the dependent variable is a discrete choice. The predicted value of adoption (M) from the logit model can be interpreted as the probability that a farm with characteristics Z drawn at random will have adopted the technology. Appendices 2-B and 2-C describe the coeffient interpretation and goodness-of-fit measures that are used in the analyses.

Although more innovative econometric techniques can be used with data for some regions or crops, the comprehensive and consistent look at all the Area Studies survey data required the use of relatively simple adoption models. We used the logit models described in appendix 2-A to analyze the adoption of the management technologies and practices (for nutrients, pests, soil, and water) presented in chapters 3 through 6.

Core Set of Variables

Multiple factors affect a farmer's decision to adopt production management practices. We chose a core set of variables that we used in each analysis. This set represents the factors most often cited in the literature as important determinants of adoption decisions. One goal of the Area Studies analysis was to assess how the influence of factors may vary by practice or region.

Farmers have an incentive to adopt management practices that increase the profitability of their cropland by reducing costs or increasing yield. The variables selected for the nutrient, pest, soil, and water management adoption models reflect the characteristics of the agricultural producer and the farm. These variables represent factors such as human capital, production systems, agricultural policies, climate, and the natural resource attributes of the sampled field.

[5] In most cases the technology adoption decision is simply a yes/no rule, i.e., either to adopt or not. In these cases the binomial logit model is used. If a farmer is faced with a choice among several competing alternatives, such as with tillage systems, then the multinomial logit model is used (see appendix 2-A).

Table 2.2—Description of core set of variables

Human capital
COLLEGE = 1 if respondent had at least some college education, 0 otherwise
EXPERIENCE = the number of years of operating experience
INSURE = 1 if the respondent had crop insurance, 0 otherwise
WORKOFF = the number of days per year the respondent worked off the farm
TENURE = 1 if respondent owned the field, 0 otherwise
Production characteristics
ACRES = the number of acres operated by the respondent
ROTATION = 1 if the respondent used crop rotations for pest management, 0 otherwise
DBL-CROP = 1 if the respondent cultivated more than one crop in the field during the survey year, 0 otherwise
IRRIGATION = 1 if the respondent irrigated, 0 otherwise
Agricultural policies
PROGRAM = 1 if the respondent participated in a Federal commodity program or CRP, 0 otherwise
ADVICE = 1 if the respondent sought advice or assistance, 0 otherwise
Natural resource characteristics
SLP = a value between 0 and 190, with values closer to 190 indicating soils that are highly leachable
EROTON = total soil erosion levels in tons per acre per year
RKLS = sheet and rill soil erosion levels in tons per acre per year
WIND = wind erosion levels in tons per acre per year
PISOIL = a value between 0 and 1, with values closer to 1 indicating highly productive soils
Climate
RAIN = average monthly inches of rainfall normalized over a 30-year period
TEMP = average monthly temperature (degrees Fahrenheit) normalized over a 30-year period

The complete set of variables varies somewhat in each of the adoption models depending on the resource management practice investigated. However, some variables are common to each of the adoption models, and this section provides a description of these core variables (table 2.2). We recognize that a single set of core variables is quite restrictive for some applications. However, the unified analysis offers the opportunity to do cross comparisons in a way that cannot be done with different models and different definitions for variables. Variables specific to a resource management practice will be discussed in the individual sections containing the adoption models.[6]

Farmer Characteristics

Human capital variables, such as education level and years of experience are proxies for a farmer's ability to acquire and effectively use information about new agricultural production technologies. The growing complexities of some resource management technologies may increase the need for specialized skills (Gladwin, 1979). Securing the appropriate technical skills may increase the costs of applying a new technology since it could require educational investments or the hiring of managers or contractors (Welch, 1978). Farmers with higher levels of human capital are expected to be more likely to adopt complex technologies.

[6] The adoption analyses are based on the agricultural acres devoted to cropland. If all of the acres in the sampled field were devoted to either pasture, rangeland, CRP, fallow, idle, set-aside, wetland, woodland, or forage, then these observations were not included in the analysis. Statistical descriptions of the variables and the areas differ depending on the number of observations in the model. The descriptions presented in the report are based on weighted means of cropland samples. The sample means for the variables in the models are weighted by the "a-weight" variable which weights the area-frame samples by agricultural acres represented in an area. The total number of usable cropland observations is 6,960.

The education variable (COLLEGE) is a binomial variable. A value of 1 was assigned to producers with at least some college education (i.e., had some college education, had completed college, or had attended graduate school), and a value of 0 was assigned to farmers with less than a college education. About 44 percent of the respondents had at least some college-level education. A higher education level is expected to increase the probability that a farmer will adopt management practices that require advanced technical skills. Schultz (1975) argued that education and experience were distinct influences in one's adjustment to change.

The number of years of farming experience (EXPERIENCE) could positively or negatively affect the likelihood that a farmer would adopt resource-conserving technologies. Farmers who have been agricultural producers for many years are expected to be more efficient at incorporating new technology into production. However, long-time farmers may actually be more reluctant to switch from technologies they have used efficiently for many years. Huffman and Mercier (1991) in a study of the adoption of computer technologies in agriculture found that experience with new technologies was highly correlated with more education, but not necessarily with age or years of operation. Also, long-term farmers are generally older and have shorter time horizons for collecting the benefits from adopting new technology. The average number of years of farming experience for all areas combined was about 24 years. Age and experience are highly correlated, however, so operator age was not included as a variable in the analysis.

Farmers who own their agricultural land are often assumed to be better stewards when it comes to preserving natural resources associated with the long-term productive capacity of agricultural land. Security of land tenure may be necessary for making capital investments in new technologies (Feder, 1985). The survey included questions on whether or not the farmer owned the sampled field (TENURE).[7] About 39 percent of the cropland acres were owned by the farmer. Landownership is expected to have a positive impact on the adoption of technologies with high fixed costs.

Some farmers also work off the farm (WORKOFF) to supplement income earned by farm activities. In the Area Study sample, farmers worked off the farm an average of 32 days per year. It is expected that the more they work off the farm, the more likely are farmers to adopt time-saving technologies and the less likely are they to adopt time-intensive technologies. The Feder, Just, and Zilberman (1985) review of adoption studies showed mixed results with respect to tenancy and off-farm employment.

Another operator characteristic of interest is his or her level of risk aversion. Crop insurance programs provide protection from losses in crop yields due to adverse weather and pest infestations. Farmers who have crop insurance (INSURE) may find it less risky to invest in resource management technologies. For example, farmers may be motivated to try pest management strategies that reduce pesticide use if they are likely to receive compensation for severe crop damages. Farmers who apply for crop insurance may be more risk averse and would be less likely to adopt new, and potentially risky, technology without the availability of insurance. We recognize that the purchase of crop insurance is only a weak proxy for risk aversion.

Production Characteristics

The effect of farm size (ACRES), or acres operated, on the adoption of farming practices has long been debated. Many argue that new agricultural technologies often have a scale bias that favors larger farms and that adoption of these technologies will accelerate the decline in the number of small farms. Although theory provides little guidance on the relationship between farm size and investments in new technology, empirical studies often find that larger farms are more likely to adopt new technology than smaller farms (Marra and Carlson, 1987; Feder and O'Mara, 1981; Just and Zilberman, 1983). One reason could be that larger farms may have lower information or management costs per unit of output. In developing countries, small farm sizes may constrain the adoption of certain technologies, and credit constraints may contribute to a scale bias (Roth, Wiebe, and Lawry, 1992). Many of the technologies and practices analyzed in the Area Studies Project probably would not impose a scale constraint on the farmers surveyed. Respondents in the sample operated an average of 1,697 acres.

Adoption of resource management practices can be driven by the type of crop that is grown and the cropping practices that are used. The type of crop can influence chemical and nutrient applications and water and soil management decisions. For example, row crops are considered to be more erosive to soil than

[7] The survey also contained questions about the total number of acres owned, rented, or rented out by the operation, but this information could not be incorporated into the analysis of field-level production decisions.

small grains, and fruit and vegetable crops can require larger quantities of water. A crop variable was included in each analysis, but since the definition differs for every model, the variable is not explicitly included in the core set.

Since planting the same crop over many years can increase pest problems and deplete nutrients, crop rotations (ROTATION) are used as pest and nutrient management strategies.[8] Crop rotations were practiced on about 32 percent of the cropland. Cropping practices such as double-cropping indicate production intensity. Cultivating more than one crop on a field per year, double-cropping (DBL_CROP), can intensify the use of natural resources and may motivate the adoption of management practices to reduce the impact on natural resources. Double-cropping may also be used as a risk-reduction strategy (Marra and Carlson, 1987). The use of irrigation (IRRIGATION) is another production characteristic that may affect the applicability and effectiveness of certain cropping practices.[9]

Agricultural Policies

Agricultural and environmental policies and regulations can affect the profitability of a farmer's using a set of resource management practices and thereby alter incentives for adoption. Commodity programs that existed during the survey period distorted relative factor and commodity prices for certain crops (Ribaudo and Shoemaker, 1995).[10] Program enrollment could also have had a negative influence on farmers' use of crop rotations because planting a nonprogram crop on base acres resulted in the loss of program eligibility (Reichelderfer and Phipps, 1988). Another important policy influence on technology choice was through conservation compliance. Producers with highly erodible land were required to develop a conservation plan for their acreage and follow recommended practices or risk losing benefits from farm programs. Enrollment in a commodity program (PROGRAM) was used to capture these policy factors. The survey question about program participation was general, however, so we do not know how many or which programs were chosen by the producer.

Farmers can learn about new agricultural technologies and receive assistance from both the public and private sectors. Feder, Just, and Zilberman (1985) found that the extent of effort to gain information is a function of the expected gain from that knowledge. For example, the USDA Extension Service and the NRCS provide information and technical assistance to farmers about agricultural and resource management practices, but farmers will not seek that information unless the potential gain is perceived as significant. Agricultural firms typically supply information about new products, and private contractors can be hired to provide technical assistance. For some of the management practices being examined, such as those used for pest management, the farmers were surveyed to determine whether they used hired staff, the extension service, or some other source of pest management information. Saltiel, Bauder, and Palakovich (1994) found that access to information "plays a stronger role in the adoption of management-intensive practices than it does for low-input methods." The access to advice may not always lead to a better outcome for welfare or the environment, however (Stoneman and David, 1986; Mitra, 1997). Advice that is designed to increase profits may result in the use of practices that lead to a higher amount of residuals reaching sensitive environmental resources. When available, a variable denoting whether or not a farmer received advice (ADVICE) was included in the adoption models.

Natural Resource Characteristics

The compatibility of a resource management practice with an individual farm depends on how the technology will perform given the resource endowments of a field, such as soil quality and climate. A set of indices was developed to describe the natural resource characteristics unique to each of the sampled fields. The indices were generated using the 1992 NRI database to characterize land vulnerability to erosion (EROTON) and chemical leaching (SLP). A measure of soil productivity (PISOIL) was also derived.

These broad resource indices were used in the comprehensive modeling effort to see whether general indica-

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[8] In the pest management adoption models, factors affecting the adoption of crop rotations are analyzed, and therefore, it is a dependent variable for that model.

[9] For most of the adoption models, irrigation is treated as an exogenous (i.e., predetermined) variable. In Chapter 6, however, we examine the farm and natural resource characteristics that may influence a farmer's use of irrigation itself.

[10] Prior to the 1985 Farm Bill, deficiency payments were a function of actual yield, so there was a strong incentive for enrolled producers to increase the use of inputs such as chemicals to increase production. The 1985 Farm Bill "decoupled" the payment from actual yields by basing the payment on a fixed yield. However, Ribaudo and Shoemaker (1995) clearly show that distortions in relative prices remained because the effective cost of land was increased due to the set-aside requirement.

tors will capture the influence of resource characteristics on adoption across all areas and technologies. Individual models of particular crops, areas, and technologies contain specific resource characteristics. When detailed resource information is available, it should be used to assess the impact of specific characteristics on adoption. In many circumstances, however, only county averages or broad indices are available. The Area Studies data set offered the opportunity to observe the information loss that may result from using aggregate measures to study the influence of production-impact resource factors (i.e., factors that may influence crop yields and profits) on adoption.

The measures of erosion and leaching also capture some environmental-impact characteristics that would not directly influence decisions based on production profits, but would indicate potential environmental consequences of the decisions that are made. For example, a high level of leachability may have no impact on a pest management decision (and would not be significant in our models), but would be an indicator that chemical-intensive pest control practices may threaten groundwater quality.

Soil Erosion Soil erosion has implications for water quality and the long-term productivity of cropland. The Universal Soil Loss Equation (USLE) from the 1992 NRI measures annual soil loss from sheet and rill erosion in tons per acre per year. The USLE is a measurement of the physical characteristics of an area, such as soil type and weather, and the choice of management practices that may contribute to or prevent soil erosion. The USLE is a multiplicative relationship with the following form:

$$USLE = (RKLS) * C * P \qquad (2)$$

where *R* measures rainfall, *K* accounts for soil type, *L* measures slope length, and *S* is slope steepness. *C* and *P* are management factors that take account of cropping pattern, tillage system, and supporting conservation practices (Wischmeier and Smith, 1978).

The inherent soil erodibility of a field due to rainfall (sheet and rill) is captured by the *RKLS* term. The *RKLS* term measures sheet and rill erosion for a fallow field that is plowed in the direction of the slope. Actual erosion can be reduced by crop management practices and conservation efforts, which are captured by the *C* and *P* variables in the *USLE*. The value of *C* is determined by crop, rotation, and tillage choices, and *P* is a measurement of conservation practice use, such as stripcropping and contour farming. *C* and *P* values range from 0 to 1, with lower values associated with higher conservation effort. In practice, few cultivated fields have actual erosion rates of *RKLS*. For example, corn grown using a moldboard plow may have a *C* factor of around 0.5 to 0.6, indicating that without further conservation efforts, actual erosion would be 50 to 60 percent of potential erosion. Furthermore, investment in conservation may not completely eliminate erosion. No-till corn, for example, may have a *C* factor between 0.1 and 0.2, indicating that erosion may still occur at 10 to 20 percent of *RKLS* if nothing further is done. Also, the *RKLS* term itself can be affected by the adoption of conservation practices, such as terracing, that changes the slope length, *L*. While the effect of soil conservation practices on erosion is very site-specific, a good soil conservation management plan might be expected to reduce actual erosion by around 60 to 80 percent of the amount indicated by *RKLS*. For this study, wind erosion rates (WIND) were also obtained from the 1992 NRI database. In the empirical analysis, a variable was constructed (EROTON) that represents total soil erosion potential in tons per acre per year. EROTON was calculated by combining potential soil loss from sheet and rill and wind erosion.

Soil Leaching Potential One measure of environmental vulnerability is the inherent potential of soil to leach chemicals into ground water. The soil-leaching potential (SLP) variable used in the Area Studies analysis is based on an index developed by Weber and Warren (1993). The potential for chemicals to leach from the root zone depends on characteristics of the chemical and of the soil. SLP does not include characteristics of any particular chemical, so it cannot be used to compare leaching potentials of specific fertilizers or pesticides in interaction with the soil associated with the observation. High soil leachability reduces the availability of an applied chemical for crop production and increases the availability of the chemical for transport to the environment. Soil texture will determine the mechanical ability of dissolved chemicals to travel downward. Soil acidity (measured as pH) determines the mobility and degradation of chemicals, and organic matter can adsorb the chemicals in the upper soil layers. Therefore, the soil characteristics used to construct the SLP measure are texture, pH, and organic matter. The index is a value between 0 and 190 where SLP=190 represents the highest level of leachability. Weber and Warren categorized the SLP values between 135 and 190 as "High," between 100 and 134 as "Moderate," and values below 100 as "Low." SLP is expected to play a role in affecting the choice of pest, nutrient, and water management strategies. For example, the higher the SLP value, the sandier the soil and

the more likely that chemicals will leach. If a pest or nutrient management strategy is adopted to limit chemical applications, then it is expected that highly leachable soils may induce adoption. Additionally, since highly leachable soils do not retain water adequately, these soils may dry out more easily, requiring the use of irrigation technology.

Soil Productivity Index In addition to the environmental indices, a variable was created to represent soil quality, or the productive capacity of soil. Highly productive soils may provide the impetus to use soil conservation practices that keep soil from leaving the field. In addition, highly productive soils better retain water, and therefore may not require the use of irrigation.

Pierce et al. (1983) developed a model to measure long-term productivity losses from soil erosion using information from the NRI and SOILS-5 databases. This model can be used to calculate a soil productivity index (PISOIL) based on soil depth and the sufficiency of soil characteristics for plant growth. The values of PISOIL range between 0 and 1:

$$PI = \sum_{i=1}^{n} WF_i * A_i * B_i * C_i \qquad (3)$$

where WF_i is a weighting factor for soil horizon i based on its depth; A_i is the sufficiency of the available water capacity for horizon i; B_i is the sufficiency of bulk density; C_i is the sufficiency of pH; and n is the number of soil horizons or layers in the root zone. Each of these factors reduces crop yield only when it falls below some threshold. If a factor is equal to or greater than the threshold, then it does not limit crop yield. If all factors are equal to or greater than the threshold for all soil horizons, and soil depth is at least 100 cm, then the value of PISOIL achieves a maximum of 1.00.

Climate

Climate can be an important factor for determining the performance of an agricultural technology. Average monthly rainfall (RAIN) and temperature (TEMP) were calculated over a 30-year period.[11] It is expected that higher average rainfall will be associated with decreases in irrigation use and a greater need for soil conservation in areas with high sheet/rill erosion rates. On the other hand, drier areas with higher average temperatures and lower average rainfall levels may be associated with both an increased need for irrigation and soil conservation on fields subject to wind erosion. Soil conservation practices that leave crop residues on the ground may also protect soil against drought conditions that occur in dry climates. In regions with high average temperatures and rainfall, humid conditions can contribute to increased pest levels. Increased pest levels may require greater investments in pest management strategies.

Area Dummies

In the combined-areas models, an intercept dummy variable representing each region was included for model estimation since regional comparative advantage may not be covered thoroughly by the socioeconomic or natural resource variables. The regional dummies incorporate characteristics unique to each area that are not explicitly incorporated into the model, such as regional price variations. To prevent collinearity in estimation, the dummy variable representing the White River Basin was dropped in each model. This means that the partial derivatives and the significance levels of the area dummy variables are relevant only for comparisons to the White River Basin. To simplify the discussion, the area dummy results were not included in the tables for the combined-areas models.

The following four chapters present the results of the empirical analyses of management practices using the unified modeling framework and set of core variables described above.

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[11] We recognize that temporal variation of climate and extreme weather events have a strong influence on producer decisions, but incorporation of such factors is beyond the scope of this study.

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Appendix 2-A: Logit Models

Binomial Logit Model

We assume that a farmer adopts a new technology if the utility (benefit) the farmer receives is greater with adoption and otherwise does not. Let M_i=1 if the farmer has adopted management technology or practice i and M_i=0 otherwise. The utility or profitability of adoption is hypothesized to be a function of a set of exogenous variables Z. Technology adoption can be characterized as:

$$M = Z'\gamma + \varepsilon \qquad \text{(2A-1)}$$

where γ is a vector of parameters and ε is an error term that includes measurement error and unobserved factors that affect adoption (Amemiya, 1981). In the binomial logit model, the probability of adoption is given by:

$$\text{Prob}\,(M_j = 1) = \frac{e^{\gamma' Z}}{1 + e^{\gamma' Z}} \qquad \text{(2A-2)}$$

where *e* is the exponential function. A detailed interpretation of model coefficients is presented in appendix 2-B and goodness-of-fit measures used for the logit models are described in appendix 2-C.

Multinomial Logit Model

In the multinomial logit model, the decision to adopt a management technology is modeled as a discrete choice among J+1 alternatives (i.e., j = 0, 1, 2,. . . J). M_j takes on a value of 1 if management technology or practice j is adopted and 0 otherwise. The probability P_j that a farmer with characteristics Z adopts technology j is given by:

$$P_j = \text{Prob}\,(M_j = 1) = \frac{e^{Z'\beta}}{1 + \sum_{j=1}^{J} e^{Z'\beta}}, \quad j = 1...J \qquad \text{(2A-3)}$$

where β is a vector of parameters which satisfy $\log(P_i/P_j) = \beta_i - \beta_j$ (McFadden, 1974). Note that the model has been normalized on M_0, since the probabilities sum to one, once probabilities for M_1 through M_J are known, M_0 is given.

Appendix 2-B: Interpreting Model Results

The coefficients from the logit model are used to calculate the partial effects of the exogenous variables on the probability of adoption (Maddala, 1983). The partial effects are calculated as:

$$\frac{\partial P}{\partial Z_k} = \frac{e^{\overline{Z}'\gamma}}{(1+e^{\overline{Z}'\gamma})^2} * \gamma_k \qquad \text{(2B-1)}$$

where P is the predicted probability of adoption; $\overline{Z}$ is the mean vector of the exogenous variables in Z; γ is the set of corresponding coefficients obtained from the logit adoption model, and Z_k and γ_k are the kth elements of Z and γ, respectively. The partial effect can be interpreted as the change in the predicted probability of adoption, given a unit change in the variable Z_k. For binomial (dummy) variables which take on a value of either 0 (no) or 1 (yes), the interpretation of the coefficient is clear. For continuous variables, the value of the partial effect is in the same unit as the continuous variable. In order to obtain a unitless and comparable measure, the continuous variables were converted into elasticities. Elasticities are values that show how predicted probabilities change with a 1-percent change in the sample mean of the variable. An elasticity e_{pk} for a continuous variable is given by:

$$e_{pk} = \frac{\partial P}{\partial Z_k} * \overline{Z_k} \qquad \text{(2B-2)}$$

where $\overline{Z}_k$ is the mean value of variable Z_k. The elasticity e_{pk} measures the change in the predicted probability of adoption given a 1-percent change in the variable mean. Another way of interpreting the results of the logit model is to calculate the predicted probabilities directly from equation 2A-2, using selected values for the variables Z. The predicted probabilities of adoption calculated at the sample means of the variables provides a benchmark for comparing how modifications in the exogenous variables affect adoption probabilities. The values of one or more of the variables in Z can then be varied (holding other variables constant at their mean values) to determine how those changes affect the probability of adoption.

Appendix 2-C: Goodness-of-Fit Measures for Logit Models

Since the logit model is a non-linear model, the normal R^2 measure for goodness-of-fit is not valid. Several alternative measures have been proposed in the literature for measuring the goodness-of-fit of logit models. Two of the most commonly-used measures are (1) percent of correct predictions, and (2) McFadden's pseudo-R^2. To determine the percent of correct predictions, the predicted probability of adoption is calculated for each farm and the prediction is compared with the actual adoption decisions. The model is assumed to predict adoption if the predicted probability is greater than 0.5, and to predict non-adoption otherwise. McFadden's pseudo-R^2 (R^2_m) is based on comparing the value of the likelihood function from the model to the value of the likelihood function when all coefficients other than the constant term are restricted to zero:

$$R^2_m = 1 - \frac{\log L_\Omega}{\log L_\omega} \qquad \text{(2C-1)}$$

where $\log L_\Omega$ is the log likelihood of the regression and $\log L_\omega$ is the restricted log likelihood.

A recent assessment found that these measure may perform poorly (Windmeijer, 1995). A better measure is Veall and Zimmermann's pseudo-R^2, given by:

$$R^2_{VZ} = \frac{2(\log L_\Omega - \log L_\omega)}{2(\log L_\Omega - \log L_\omega) + n} * \frac{2\log L_\omega - n}{2\log L_\omega} \qquad \text{(2C-2)}$$

where $\log L_\Omega$ and $\log L_\omega$ are defined as before and n is the sample size of the model.

3. Nutrient Management

In this chapter, we briefly describe the role of fertilizer use in U.S. agriculture and why residual nutrients reaching ground- and surface-water sources are a concern. The Area Studies survey data are described with respect to the amount of fertilizer applied, use of nutrient management practices, and sources of information used for making fertilizer application decisions. The results of the simple adoption models for selected nutrient management practices are reported for the combined-areas and single-area models using the modeling framework and core variables described in chapter 2. The human capital, production, agricultural policy, natural resource, and climate factors affecting adoption are described.

The United States saw a virtual explosion in crop yields during the 20th century. Each U.S. farmer, on average, produces enough food for himself and at least 60 other people. Average corn yield quadrupled, and average yields of wheat, soybeans, cotton, and other important crops more than doubled in the last 50 years. This level of production was reached primarily for two reasons: The use of commercial fertilizers that provide low-cost nutrients, and the development of high-yielding crop varieties and hybrids.

The yield potential of a crop is determined by the most limiting of the various factors essential for plant growth. These factors, in addition to plant nutrients, include moisture, temperature, light, and plant density. Plant nutrients are divided into three categories: (1) primary nutrients, (2) secondary nutrients, and (3) micronutrients.[1]

Soil fertility has been of vital concern to farmers since the beginning of agriculture. Historically, farmers settled in areas where soils were rich in nutrients. Producers either included the land in a fallow rotation or farmed until the fertility was exhausted and then moved on. Eventually, the cost of land increased so that there were fewer economic opportunities to fallow or abandon land. As the demand for agricultural commodities increased, generated by an expanding population and economic development, farmers began to replace nutrients that were taken from the soil by extensive farming. Farmers applied manure and other farm refuse to the soil to replenish nutrients before the advent of commercial fertilizers (The Fertilizer Institute, 1976).

Chemical fertilizers contributed significantly to the increase in U.S. agricultural productivity, but use of these chemicals has been associated with environmental, human health, and economic concerns (Kellogg et al., 1992). Most commercial fertilizers contain nitrogen (N), phosphate (P_2O_5), and potash (K_2O). Nitrogen is the key element of increased yields and is usually used in the largest quantity. Crops are estimated to absorb nitrogen from commercial fertilizers at a rate from 30 to 70 percent. The portion of nitrogen that is not absorbed by the plants is free to escape into the environment (Legg and Meisinger, 1982). Residual N by itself does not necessarily result in environmental problems (Ribaudo, 1997). Potential damages will depend on soils, climate, and the nutrient management practices that are used. The runoff and leaching of nitrogen into rivers, lakes, and estuaries is a major contributor to water quality problems (Puckett, 1994). The U.S. EPA (1998) identified nutrient loadings as stressing 15 percent of surveyed river miles and up to 20 percent of lake acreage. Agriculture was the leading contributor of those nutrients. High nitrate concentrations in drinking water may pose human health risks. The adoption of certain nutrient management technologies by farmers has been promoted as a way of obtaining more efficient use of nitrogen fertilizer and of reducing the quantity of residual nutrients available for transport to the environment. Huang (1997) presents a comprehensive summary of nutrient management issues.

Summary of Nutrient Management Practices and Data

In this section, we describe the data on nutrient management obtained from the Area Studies survey. Fertilizer use and the practices and information sources that are used to manage fertilizer applications are presented.

[1] There are three primary nutrients, nitrogen (N), phosphorus (P), and potassium (K), which are needed in large amounts. The three secondary nutrients, calcium (Ca), magnesium (Mg), and sulfur (S), are applied to correct soil pH. These are as important as primary nutrients but are applied in smaller amounts. Micronutrients are essential to plant nutrition but are needed in even smaller amounts. The seven micronutrients are boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn).

Fertilizer Use

The rate of commercial fertilizer application depends on a variety of factors including soil type, climate, crop mix, crop rotation, irrigation, feasible technology, government programs, and commodity and fertilizer prices (Taylor and Huang, 1994). Of the factors affecting fertilizer use, crop mix may be the most important. In the Area Studies survey sample, nitrogen was applied to 99 percent of the potato and 96 percent of the corn planted acreage, while only 21 percent of the soybean acreage received nitrogen fertilizer applications. Potatoes and corn are crops that utilize large amounts of soil nitrogen in the production of their yields, whereas soybean, a legume[2] with the ability to extract nitrogen from the air to use for the production of its yields, needs very little added soil nitrogen. Crops also differ in the amount of phosphate and potash that are required. Table 3.1 shows the extent of chemical fertilizer usage by major nutrient elements (N-P-K) in the Area Studies data by major crop group.

The pounds of chemical fertilizer used per acre and the expenditures on chemical fertilizer per acre vary greatly by crop mix. Corn growers use, on average, 136 pounds of nitrogen per treated acre, whereas potato growers apply 232 pounds of nitrogen per treated acre. Figure 3.1 shows the distribution of pounds of commercial fertilizer applied on a per acre basis by fertilizer element (N-P-K) and crop. Fertilizer nitrogen application rates vary by region for the same crop due to different soil types and climatic conditions which affect farmers' production practices (irrigation, tillage type, plant variety). For example, average nitrogen applied to potatoes in the Snake River Basin is 234 pounds per treated acre versus 318 pounds per treated acre in the mid-Columbia River Basin. There is less variation in the average amount of nitrogen applied to corn. Figure 3.2 shows some of the regional differences in pounds of nitrogen fertilizer applied per treated acre to the same crop mix.

[2] Legumes are plants that bear nodules on their roots that contain nitrogen-fixing bacteria of the genus *Rhizobium* and therefore have the unique ability to fix nitrogen to the soil.

Table 3.1—Percent of acres for major crops receiving fertilizer applications—combined areas

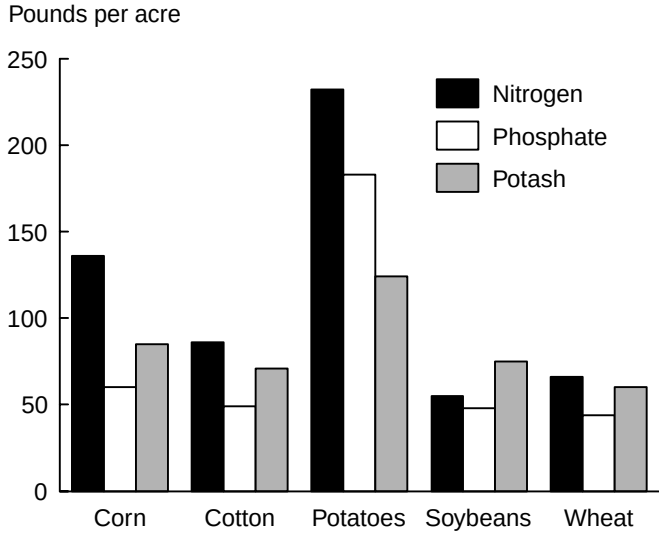
Crop	Nitrogen (N)	Phosphate (P_2O_5)	Potash (K_2O)
		Percent	
Corn	96	78	70
Cotton	90	62	60
Potatoes	99	98	75
Soybeans	21	24	25
Wheat	77	42	15

Nutrient Management Practices

Selected nutrient management practices have been designed to help farmers manage fertilizer use more efficiently, while obtaining desired crop yields. Some of these practices are intended for a particular type of farm operation. For example, the use of animal waste for fertilizer may be most profitable only if there is an onfarm or nearby source of manure. The specific practice, or combination of practices, that a farmer will choose depends on the type of crop grown (legume or non-legume) and the type of farm (livestock operation or not). The box on the following page provides definitions of the nutrient management practices analyzed using the Area Studies survey data.

We divided the nutrient management technologies analyzed in this study into two categories: *modern* nutrient management practices and *traditional* nutrient management practices. As the name suggests, modern nutrient management practices are newer technologies that are more information intensive or require a higher level of technical expertise than older practices. For this analysis, we included soil or tissue N-testing, split nitrogen applications, and an aggregate category that included one or more of three practices (N-testing, split nitrogen applications, micronutrient use) as "modern practices" for convenience. *Traditional* nutrient management

Figure 3.1
Average pounds of fertilizer applied per treated area

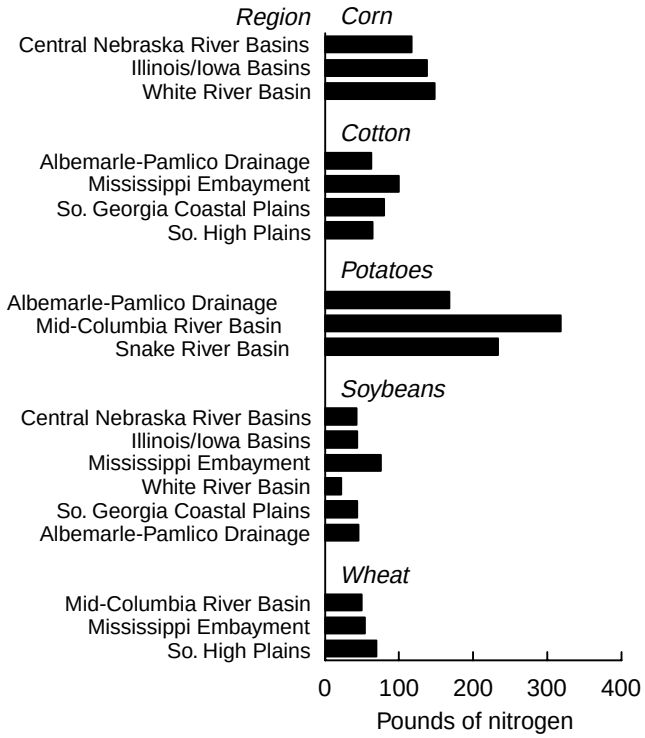


practices are technologies that have been used effectively for at least several decades. *Traditional* practices include the planting of legumes in rotation with other crops and the use of manure to provide organic fertilizer for crops. The adoption of both modern and traditional practices would be expected to reduce the application of chemical fertilizers. The modern technologies increase the application efficiency, and the traditional ones substitute organic sources of nutrients for chemical fertilizers.

The adoption rates for the various nutrient management practices in the Area Studies survey are shown in table 3.2. The most common practice category was the combination of three practices (modern practices), with a 44 percent level of adoption. Soil N-testing, split nitrogen applications, and micronutrients each had an adoption level of approximately 20 percent, and producers could use more than one of these methods. There was more variation among traditional technologies. In the sample, 37 percent of the acreage was cultivated using legumes in rotation and more than 9 percent using manure.

Adoption rates for nutrient management technologies also varied greatly depending on the crop grown (fig.

Figure 3.2
Average pounds of nitrogen applied per treated acre for selected regions by crop



Glossary of Nutrient Management Practices

Modern practices (three practices together) includes the use of a single or any combination of the nutrient management practices that are technologically advanced or more modern. These include N-testing, split nitrogen applications, and the use of micronutrients (see below for definitions).

N-Testing refers to soil and plant tissue N tests used by farmers to estimate the residual nitrogen available for plant use in determining fertilizer needs. Soil testing before planting includes estimation of nitrogen in the root zone of the crop being planted. For corn grown in certain areas, the root zone can be 3 feet or more.

Split Nitrogen Applications refers to applying half or less of the required amount of nitrogen for crop production at or before planting, with the remainder applied after emergence. Multiple applications supply nutrients more evenly and at times when the crop can most efficiently use them.

Micronutrients refers to applying micronutrients to the field either alone or mixed in bulk blended fertilizer. Micronutrients are essential to plant nutrition but are needed in relatively small amounts. Judicious use is also important because some of the micronutrients (boron, copper, and molybdenum) can be toxic if applied in excess or to the wrong crop.

Legumes in Rotation refers to practice of growing leguminous crops (soybeans or alfalfa) in rotation with other crops (non-leguminous). This type of cropping pattern is used to improve soil fertility. For the purpose of this study a farmer is said to use legumes in rotation, if a non-leguminous crop is planted in the field one year, where a legume was planted the previous year, or a leguminous crop is planted in the field where a non-legume was planted the previous year. For this study, leguminous crops are defined as alfalfa or soybeans, and non-leguminous crops are any crop excluding hay and pasture.

Manure refers to applying animal manure to the field as a source of nutrient replacement. Use of animal waste as fertilizer is economically feasible only if onfarm or nearby sources exist.

3.3). The technology of N-testing was adopted by 79 percent of the potato farmers, but only 23 percent of the corn and wheat farmers used N-testing. Another example is the adoption of legumes in rotation, a technology used by 48 percent of corn growers compared with 14 percent of small grain farmers. On the other hand, the adoption of split nitrogen application was the most consistent across all crops, ranging from a low of 14 percent for corn to a high of 25 percent for cotton. Crop dummies were used in the analysis (ROW, SMGRAIN, CORN, COTTON, RICE, SOYBEANS, POTATOES, WHEAT, PEANUTS) to capture the crop-specific factors affecting the adoption of nutrient management practices.

There are also regional differences in the rates of adoption of nutrient management technologies. However, these differences may be based on crop mix. For example, legumes in rotation are used on 71 percent of the cropland in the Illinois/Iowa River Basins region, predominantly a corn and soybean area, whereas only 3 percent of the cropland in the mid-Columbia River Basin employ this technology, a region dominated by wheat. The use of manure as a nutrient management practice shows regional differences which may be due to the livestock source constraint. Manure is used on less than 20 percent of the cropland for all the regions except Susquehanna, where it is used on 61 percent of the cropland. This difference may reflect the high livestock concentrations, especially dairy cattle, in the Susquehanna. Figures 3.4-3.8 display the distribution of adoption rates of nutrient management practices by area. For the adoption analysis, a variable (ANIMAL) was created to indicate whether the farm had livestock or not.

Sources of Nitrogen Fertilizer Application Information

Farmers often seek information about when to apply nitrogen fertilizer and how much to apply. The timing of application and the quantity of nitrogen fertilizer applied can greatly affect crop yields and the amount of nutrients that can be transported to groundwater or rivers and lakes. A non-optimal use of nitrogen fertilizer is an economic loss to the farmer and could adversely affect the environment. The Area Studies survey asked farmers to indicate the most important source of information they used in making their nitrogen fertilizer management decisions. The possible responses were:

(a) no nitrogen applied,
(b) fertilizer company recommendation,
(c) consultant recommendation,
(d) judgment based on crop appearance,
(e) judgment based on soil or tissue test,
(f) Extension Service recommendation,
(g) standard amount for the crop when in this rotation, and
(h) other.

Figure 3.9 shows the responses across all the survey sample, and figure 3.10 shows a distribution of the percentage of farms using each of these sources of information, by area.

For the nutrient management adoption models, a variable (ADVICE) was created to indicate whether farmers had used some outside source of information. Included in the (ADVICE) variable were: fertilizer company recommendation, consultant recommendation, and Extension Service advice. In general, we expect that farmers who receive information or advice

Table 3.2—Adoption of nutrient management practices—combined areas

Nutrient management practice	*Percent of acres*
Modern practices (any of the three practices)	44.1
N-testing	21.2
Split nitrogen applications	18.6
Micronutrients	19.7
Legumes in rotation	37.0
Manure	9.3

Figure 3.3
Adoption of nutrient practices by crop

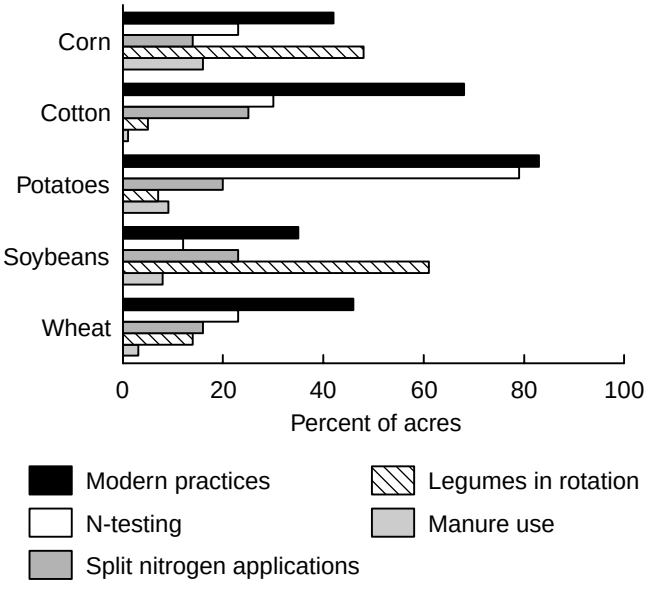


Figure 3.4
Adoption of modern practices by region

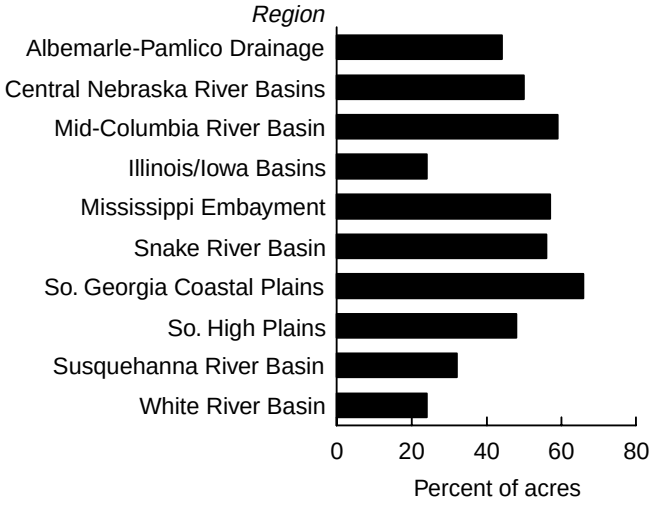


Figure 3.5
Adoption of N-testing by region

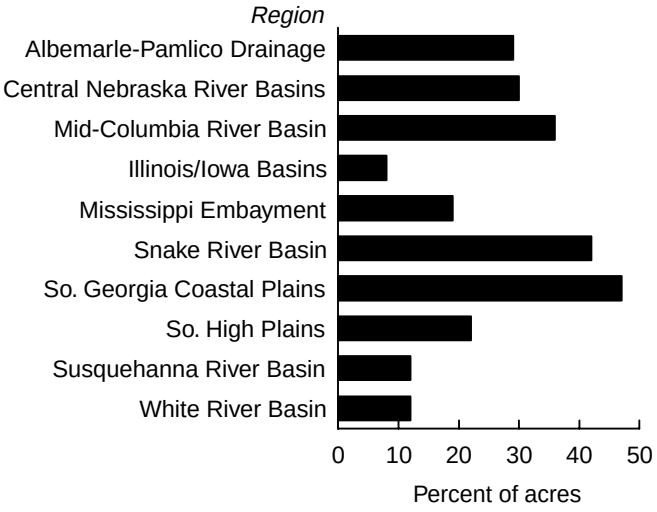


Figure 3.6
Adoption of split nitrogen applications by region

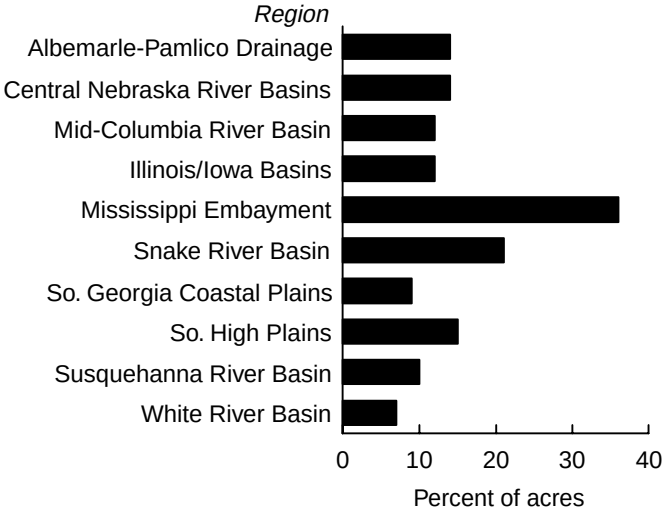


Figure 3.7
Adoption of legumes in rotation by region

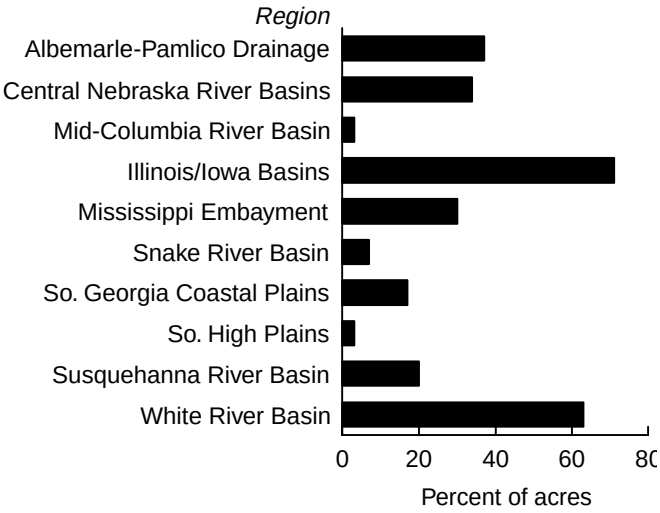


Figure 3.8
Adoption of manure use for nutrient management by region

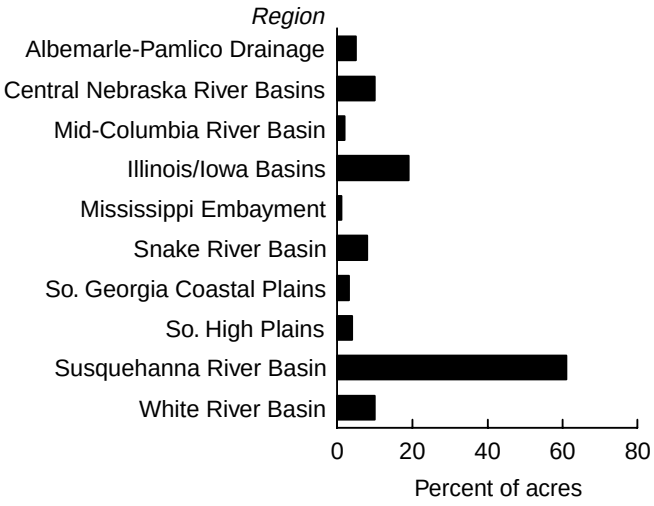
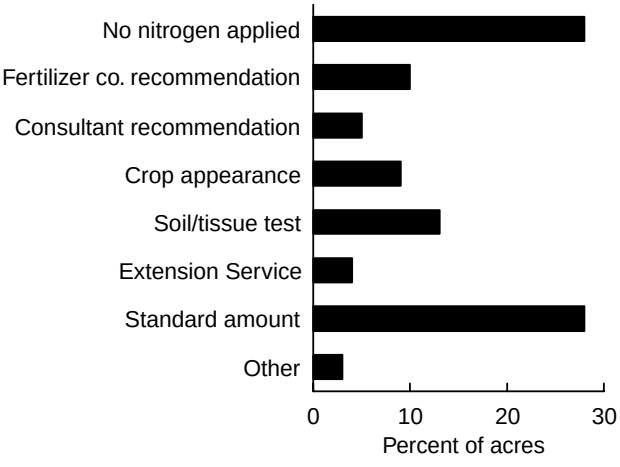


Figure 3.9
Principal sources of information for nitrogen fertilizer application decisions, all areas



from one of these three sources to be more aware of modern nutrient management technologies. The (ADVICE) variable does not include: judgment based on soil or tissue test, a more technical source of information, in which fertilizer recommendations are based on a chemical analysis of soil samples. The use of soil or tissue test (see N-testing in "Glossary," p. 29) is one of the nutrient management adoption models analyzed.

Adoption of Nutrient Management Practices

To investigate which factors affect the adoption of nutrient management practices, we selected five models of nutrient management technologies. Under the category of *modern* nutrient management practices are: (1) an aggregate practice category that includes N-testing, split nitrogen application, or micronutrient use; (2) N-testing; and (3) split nitrogen applications.[3] Under the category of *traditional* nutrient management practices are the use of: (1) legumes in rotation and (2) manure. These particular practices were chosen because they have relatively high adoption rates and they provide the best insight into the human capital, production characteristics, agricultural policy, natural resource, and climate factors affecting adoption.

For each selected nutrient management practice, adoption analysis results are reported for the combined areas (all 10 of the Area Studies regions combined) and from selected single areas. The selection criteria for choosing the regions for the single-area analyses were based on whether there were a sufficient number of observations in an adoption category. Also, the discussion refers to tables displaying the sample means, changes in percent predicted adoption, and the significance levels from the models. We present the sample means for the combined-areas and single-area models in table 3.3. Details of the modeling framework and core set of variables are presented in chapter 2.

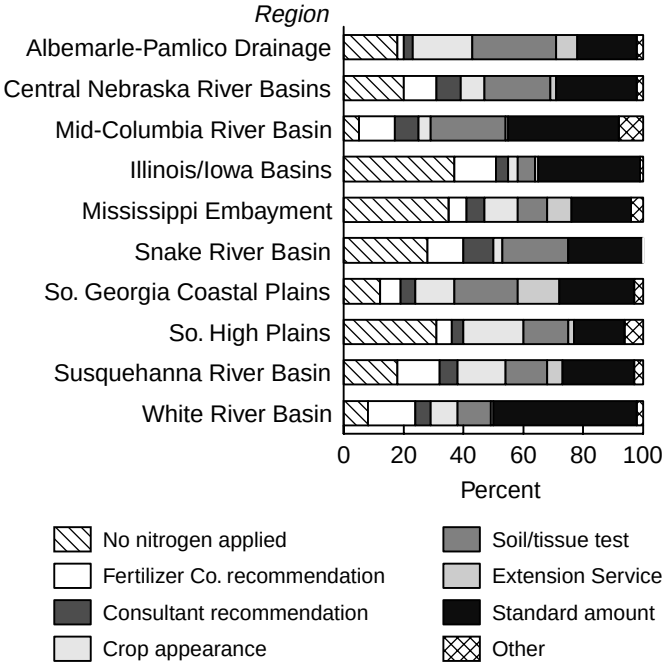
"Modern" Practices (N-testing, Split Nitrogen Applications, or Micronutrient Use)

The model results, along with the significance level, from the adoption study of the three modern practices analyzed jointly are displayed in table 3.4. For the combined-areas models, table 3.5 presents the percent predicted adoption for varying values of selected variables. The results for the adoption of N-testing and split nitrogen applications are reported in tables 3.6 and 3.7 respectively. Five regions were chosen to compare adoption results for the group of modern practices, four areas for N-testing, and only one area for split nitrogen applications based on the levels of adoption in each area.

In the combined-areas model, about 44 percent of producers used one or more of the modern practices, 21 percent used N-testing, and 19 percent used split nitrogen applications. Table 3.4 shows that the predicted adoption of the modern practices as a group was 43 percent calculated at the sample means. The percent of correct predictions for that model was 70 percent and the pseudo R^2 was 0.31. For the model of the adoption of N-testing, the predicted probability was 16 percent (table 3.6). The percent correct predictions was 79 percent and the pseudo R^2 was 0.30. The adoption model for split nitrogen application has a predicted probability of adoption of 16 percent. The percent correct predictions was 84 percent and the pseudo R^2 was 0.18 (table 3.7).

In the combined-areas models, the human capital variables, COLLEGE, EXPERIENCE, and WORKOFF, were all significant for the three practices studied as a group and indicate that more highly educated, less experienced (younger) farmers, and those who worked

Figure 3.10
Principal sources of information for nitrogen fertilizer application decisions by region



[3] The use of micronutrients is included in the "modern practice" category, but not analyzed separately.

Table 3.3—Sample means from nutrient management adoption models

Variables	Combined areas	Central Nebraska	Mid-Columbia River Basin	Illinois/Iowa Basins	Mississippi Embayment	Snake River Basin	Southern Georgia	Southern High Plains	Susquehanna River Basin	White River Basin
MODERN PRACTICES	.44	.50	.59	.24	.57	.57	.66	.48	.33	.24
NITROGEN TESTING	.21	.30	.36	.08	.19	.44	.47	.22	.12	.12
SPLIT NITROGEN APPLICATION	.19	.14	.11	.12	.36	.21	.08	.16	.10	.08
LEGUMES IN ROTATION	.38	.35	.02	.72	.30	.05	.18	.03	.20	.63
MANURE USE	.09	.10	.02	.19	.01	.10	.03	.05	.62	.10
COLLEGE	.44	.39	.70	.38	.47	.60	.39	.55	.14	.42
EXPERIENCE	24	24	22	25	23	21	25	23	22	25
WORKOFF	32	30	14	41	21	35	42	24	47	64
TENURE	.38	.43	.43	.37	.30	.63	.47	.36	.61	.40
ACRES	1702	1645	3030	912	2335	2591	1506	1974	467	933
ROW	.48	.55	.02	.58	.40	.14	.44	.75	.34	.51
SMGRAIN	.13	.03	.78	.03	.08	.49	.13	.21	.13	.06
CORN	.30	.50	.02	.57	.07	.01	.26	.07	.33	.51
COTTON	.15	00	00	00	.30	00	.15	.60	00	00
POTATOES	.01	00	.01	00	00	.13	00	00	.01	00
WHEAT	.10	.02	.67	.01	.08	.31	.09	.19	.06	.06
PEANUTS	.02	00	00	00	00	00	.23	.03	00	00
SOYBEANS	.31	.23	00	.43	.49	00	.19	00	.09	.43
DBL-CROP	.06	.01	.19	.02	.08	00	.11	.06	.04	.02
IRRIGATION	.26	.41	.25	.02	.39	.80	.26	.45	.02	00
ANIMAL	.17	.46	.01	.21	.03	.15	.15	.08	.75	.20
PROGRAM	.80	.74	.78	.85	.87	.47	.80	.92	.15	.68
ADVICE	.19	.21	.19	.19	.20	.21	.26	.12	.25	.21
INSURE	.40	.42	.57	.63	.14	.27	.32	.71	.04	.18
SLP	118	125	143	91	116	150	148	151	100	112
PISOIL	.80	.85	.87	.94	.80	.82	.37	.69	.68	.90
EROTON	33	46	59	26	19	38	16	71	50	27
RAIN	3.1	2.1	1.1	3.0	4.3	1.2	4.1	1.6	3.4	3.4
TEMP	55	49	49	50	61	44	65	58	51	52
Number of observations	6429	694	235	1269	818	509	507	505	400	743

* Refer to table 2.2 for variable definitions and units.

fewer days off-farm were more likely to adopt modern practices. The effect of education on the adoption of modern practices also was positive and significant for the Central Nebraska River Basins and Southern Georgia Coastal Plain. As shown in table 3.5, some college education increased predicted adoption to about 48 percent whereas predicted adoption was around 40 percent for farmers without any college education for the modern practice category. COLLEGE also had a positive and significant effect on the adoption of split nitrogen applications. The increased probability of adoption for modern practices by educated farmers and those who worked fewer days off-farm was expected due to the time-intensive and technical nature of these practices. The result that more experienced farmers are less likely to adopt modern practices and N-testing could indicate that long-time farmers may feel they already have sufficient knowledge to determine appropriate fertilizer needs, or perhaps they are more reluctant to switch from technologies they have used for years. Land ownership, TENURE, did not have a significant influence on the adoption of modern practices either as a group or singly. This is not unexpected since there is no longrun productivity advantage of using these methods, and either tenants or owners would gain the same benefits from adoption. Results were the same for the single-areas models.

Crop insurance reduces the risk to farmers from losses in crop yields due to events such as adverse weather or

Table 3.4—Change in percent predicted adoption of modern practices (N-testing, split N application, micronutrients)

Variables	Combined areas	Central Nebraska	Mid-Columbia River Basin	Mississippi Embayment	Snake River Basin	Southern Georgia
CONSTANT	-1.1028**	26.982**	-0.7394	-3.4064**	-1.1235**	-2.6634**
COLLEGE	0.0809**	0.2275**	0.0319	0.0471	0.0286	0.1048**
EXPERIENCE	-0.0523**	-0.0436	0.0365	-0.0401	-0.0097	-0.0623
WORKOFF	-0.0132**	-0.0085	-0.0085	-0.0166**	-0.0070	-0.0027
TENURE	0.0126	-0.0720	-0.0498	0.0092	0.0172	0.0349
ACRES	0.0109**	0.0296	-0.0332	0.0399*	0.0693**	0.08467**
ROW	0.1999**	0.3446**	—	0.1003[1]	—	0.1116**[1]
SMGRAIN	-0.0371	-0.0974	0.5755**	0.0158	0.0635	-0.1481*
COTTON	—	—	—	0.2734**	—	0.3253**
CROP	—	—	—	—	0.9071**[2]	0.2009**[3]
SOYBEANS	0.0476**	0.2213**	—	—	—	—
DBL-CROP	0.0282	—	0.2248**	—	—	0.1217
IRRIGATION	0.2574**	0.4730**	0.7539**	0.0632	0.4756**	0.1328**
ANIMAL	-0.0466**	0.0013	—	-0.0871	-0.2347**	-0.0319
PROGRAM	0.1281**	0.0701	-0.0527	0.3069**	0.1776**	0.0750
ADVICE	0.1457**	0.2873**	0.0380	0.2754**	0.2541**	-0.0949*
INSURE	0.0653**	0.0116	-0.0609	0.0602	0.0055	-0.0324
SLP	0.1079**	0.0953	-0.0205	0.1561*	0.2942	0.0183
PISOIL	-0.0178	0.1004	-0.0170	-0.0297	0.2340*	0.1043
EROTON	0.0106*	-0.0050	0.1539**	-0.0059	0.0231	-0.0016
RAIN	0.5774**	0.6751*	0.3643*	1.8758**	-0.4297**	1.9947**
TEMP	-0.1582	-7.2675**	—	—	—	—
Number of observations	6429	694	235	818	509	507
% predicted adoption	43.1	51.8	63.8	58.0	64.9	72.0
% correct predictions	70	77	75	71	75	76
Pseudo R^2 [4]	.31	.52	.35	.33	.46	.38

— Variable not included in the adoption model.
** Significant at the 5-percent level.
* Significant at the 10-percent level.
[1] ROW1 = row crops (corn, sorghum, potatoes, tobacco) except cotton.
[2] CROP1 = potatoes.
[3] CROP2 = peanuts.
[4] Veall and Zimmerman's pseudo R^2.

Note: For the table, the coefficients estimated from the limited dependent model have been converted into change in percent predicted adoption. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, RAIN AND TEMP), the reported value is the change in the percent predicted adoption given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in the percent predicted adoption between the values of 0 and 1. See Appendixes 2-A and 2-B for further details.

pest infestations. In the combined-areas model, farmers who had crop insurance were more likely to adopt one or more of the three modern practices, and more likely to adopt N-testing alone. Participation in the insurance program did not influence the adoption of split nitrogen application.

Farm size had a positive and significant effect on the adoption of the three modern practices and of N-testing for the combined areas, the Snake River Basin and Southern Georgia Coastal Plain models. Table 3.5 shows that producers who operated 5000 acres of land were more likely to adopt modern practices, about 45 percent, compared with 42 percent for farmers who operated 500 acres. The difference in predicted probability is even greater for N-testing — 22 percent compared with 14 percent for smaller operations. The effect of farm size on the adoption of split nitrogen applications was not significant. The results of these models support the argument that large farms are often associated with lower management and information costs per unit of output.

A farmer's adoption of modern practices for nutrient management may also be influenced by crop choice. We expected that farmers who cultivate legumes would have less need for adopting modern practices since they may apply small amounts of nitrogen fertilizer. The benefits of nutrient application efficiency are larger as the amounts of fertilizer increase. However, there could be a positive association with the adoption of modern practices since farmers may be growing legumes as part of a nutrient management plan, used in rotation with other crops (see following analysis of the adoption of legumes in rotation as a nutrient management practice). For this analysis, soybeans (SOYBEANS) were the only legume crops included, and the crop was produced by 31 percent of the farmers. Another group of crops, small grains (SMGRAIN), are modest users of nitrogen fertilizer. We expected small grain farmers to have less need to adopt modern practices, since these crops require relatively fewer nutrient inputs. The small grains were produced by about 13 percent of farmers and were defined as either wheat, oats, barley, or rye. Row crops (ROW) are considered the most nitrogen-intensive crop group and one would expect these farmers to adopt modern practices. Row crops were grown by 48 percent of the farmers in the Area Studies sample and were defined as either corn, cotton, potatoes, sorghum, or tobacco. Dummy variables for row crop, small grains, and soybeans (legume) were included in the combined-areas model. The model results indicate that the probability of a

Table 3.5—Percent predicted adoption—combined areas

Variables	Modern practices	Nitrogen testing	Split nitrogen application	Legumes in rotation	Manure use
College	**		**		
Yes	47.7	16.9	19.0	30.7	3.7
No	39.6	15.5	14.1	29.7	4.1
Land tenure				**	**
Yes	43.9	15.9	16.8	27.4	5.6
No	42.6	16.3	16.8	31.9	3.2
Land operated	**	**		*	**
500 acres	42.3	14.3	15.7	30.8	4.8
5,000 acres	45.2	21.6	17.3	28.4	2.4
Use irrigation	**	**	**	**	**
Yes	62.2	29.8	19.6	33.7	6.9
No	36.5	12.7	15.0	28.9	3.2
Received information	**	**	**		
Yes	55.0	25.4	15.5	30.1	3.8
No	40.3	14.5	18.9	30.2	4.0
Program	**	**	**	**	
Yes	45.7	16.7	9.9	31.4	3.9
No	33.3	14.0	18.1	25.3	4.2
Percent adoption at means	43.1	16.1	16.1	30.1	3.9

** Significant at the 5-percent level.
* Significant at the 10-percent level.

farmer's adopting one or more of the three modern practices significantly increased for farmers growing row crops or soybeans (the result for soybeans is driven by a single area). The production of soybeans also had a positive effect on the adoption of split nitrogen applications. Growing small grains did not have any significant influence on the adoption of modern practices as a group, but had a significant negative effect on the adoption of N-testing. In the single-area models, the specific crop types were significant, showing the importance of site-specific knowledge for predicting adoption.

Double-cropping is a measure of cropping intensity, and had no significant impact on the adoption of any of the modern nutrient management categories (except in the mid-Columbia River Basin model for the modern practice group), whereas the use of irrigation had an overall positive and significant effect on the adoption of all modern practices. The result was consistent with the belief that irrigated crops have the potential to reduce nutrient availability through leaching, and farmers may be less certain of the nutrient content that remains available to the crop. In addition, use of irrigation may raise a producer's average yield, which will, in turn, increase the use of inputs such as nitrogen. Therefore, we expected that a farmer who irrigated would be more likely to adopt modern nutrient management practices.

A livestock component (ANIMAL) of farm production was expected to influence the adoption of nutrient management technologies (see the following analysis of the adoption of manure-use nutrient management practice). The effect of a livestock operation on the adoption of the three modern practices and N-testing

Table 3.6—Change in percent predicted adoption of N-testing

Variables	Combined areas	Central Nebraska	Mid-Columbia River Basin	Snake River Basin	Southern Georgia
CONSTANT	-0.7604**	-0.9253**	-1.7724**	-20.574**	-1.4109**
COLLEGE	0.0135	0.0915**	0.0805	-0.0576	0.0660
EXPERIENCE	-0.0264**	-0.0468	0.0208	-0.0621	-0.0760
WORKOFF	0.0004	0.0075	-0.0038	-0.0020	-0.0088
TENURE	-0.0042	-0.0570	0.0430	0.0822	0.0394
ACRES	0.0295**	0.0022	-0.0510	0.0860**	0.0696**
ROW	0.0861**	—	—	0.9582**[1]	0.1538**
SMGRAIN	-0.0565**	—	0.3221**	0.0241[2]	-0.0222
CORN	—	0.1250**	—	—	—
WHEAT	—	—	—	0.2473**	—
SOYBEANS	-0.0011	0.1916**	—	—	—
DBL-CROP	-0.0024	—	0.1081	—	-0.0788
IRRIGATION	0.1452**	0.3397**	0.5389**	0.6716**	0.1475**
ANIMAL	-0.0467**	-0.0367	—	-0.1694*	-0.0659
PROGRAM	0.0283**	0.0429	-0.0029	0.1137*	0.0921
ADVICE	0.0863**	0.1391**	0.0564	0.4339**	-0.1641**
INSURE	0.0601**	0.1754**	0.0726	0.1704**	0.1190**
SLP	0.1174**	0.1951*	0.7994**	0.4734**	-0.2413
PISOIL	0.0643**	0.0081	-0.0536	0.1276	0.0991
EROTON	0.0057	-0.02810	0.0647*	0.0071	-0.0081
RAIN	0.0201	0.0638	0.3170	0.6523**	0.9441**
TEMP	0.0162	—	—	4.8540**	—
Number of observations	6429	694	235	509	507
% predicted adoption	16.1	21.9	34.1	42.2	45.8
% correct predictions	79	78	70	78	65
Pseudo R^2 [3]	.30	.50	.32	.58	.24

— Variable not included in the adoption model.
** Significant at the 5-percent level.
* Significant at the 10-percent level.
[1] Potatoes and sugar beets.
[2] Small grain crops (oats, barley, rye) except wheat.
[3] Veall and Zimmerman's pseudo R^2.

Note: For the table, the coefficients estimated from the limited dependent model have been converted into change in percent predicted adoption. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, RAIN AND TEMP), the reported value is the change in the percent predicted adoption given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in the percent predicted adoption between the values of 0 and 1. See Appendixes 2-A and 2-B for further details.

was negative and significant, indicating that farms with livestock operations may be less likely to adopt modern practices. This result may reflect more a grower's need to dispose of livestock waste than the use of manure for its nutrient content.

Farmers who received government farm program benefits (PROGRAM) were significantly more likely to adopt each of the modern practice categories than those who did not. The results are mixed for the single-area models. The data on participation is limited, so we cannot test whether farmers receiving program benefits are more likely to be enrolled in other USDA incentive programs that involve nutrient management. Receiving some form of outside information (ADVICE) on nitrogen fertilizer application was positively and significantly related to the adoption of each modern practice. Table 3.5 shows that agricultural producers who received nitrogen fertilizer application information had a 55 percent predicted adoption for the three modern practices, whereas producers who did not had only a 40 percent predicted adoption level. The single-area models generally had the same results. These results strongly support the hypothesis that the provision of advice may be an important determinant of adoption for technologies that require a relatively high level of information or expertise for efficient use.

Soil characteristics are important in explaining where nutrient management practices occur. Soil leaching potential (SLP) is an index that measures the potential of chemicals to leach through soil into groundwater, but can be used as a proxy for soil texture, etc. (see description in chapter 2). Typically, the higher the SLP index, the sandier the soil and the more likely that

Table 3.7—Change in percent predicted adoption of split nitrogen applications

Variables	Combined areas	Mississippi Embayment
CONSTANT	-0.9800**	-2.6886**
COLLEGE	0.0481**	0.1118**
EXPERIENCE	-0.0116	-0.0091
WORKOFF	-0.0065**	-0.0265**
TENURE	0.0010	-0.0309
ACRES	0.0070	-0.0224
ROW	0.0253*	0.0962
SMGRAIN	—	—
RICE	0.0682**	0.2173**
SOYBEANS	0.0469**	0.2036**
DBL-CROP	-0.0020	—
IRRIGATION	0.0438**	0.0132
ANIMAL	0.0159	0.0234
PROGRAM	0.0949**	0.3603**
ADVICE	0.0324**	0.1435**
INSURE	0.0073	0.0020
SLP	0.0189	0.0786
PISOIL	-0.0783**	-0.1963*
EROTON	-0.0055	-0.0371
RAIN	0.1767**	2.1879**
TEMP	0.3869**	—
Number of observations	6429	818
% predicted adoption	16.1	32.1
% correct predictions	84	71
Pseudo R^2 [1]	.18	.26

** Significant at the 5-percent level.
* Significant at the 10-percent level.
[1] Veall and Zimmerman's pseudo R^2.

Note: For the table, the coefficients estimated from the limited dependent model have been converted into change in percent predicted adoption. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, RAIN AND TEMP), the reported value is the change in the percent predicted adoption given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in the percent predicted adoption between the values of 0 and 1. See Appendixes 2-A and 2-B for further details.

Table 3.8—Change in percent predicted adoption of legumes in rotation

Variables	Combined areas	Illinois/Iowa River Basins	White River Basin
CONSTANT	0.2556**	0.0646	1.8514**
COLLEGE	0.0100	-0.0014	-0.0154
EXPERIENCE	-0.0053	0.0012	-0.0581
WORKOFF	-0.0016	0.0031	-0.0085
TENURE	-0.0454**	-0.0895**	-0.0949**
ACRES	-0.0090*	0.0149	0.0564**
DBL-CROP	0.0463	-0.2725**	-0.3702**
IRRIGATION	0.0467**	-0.2943**	—
ANIMAL	-0.0924**	-0.1085**	-0.0571
PROGRAM	0.0634**	0.0991**	0.0038
ADVICE	-0.0008	-0.0715**	-0.0091
INSURE	-0.0316**	0.0174	-0.0243
SLP	-0.2133**	-0.1496**	0.0734
PISOIL	0.2011**	0.0218	-0.2452
EROTON	-0.0040	-0.0140	-0.0100
RAIN	-0.1300	0.1464	-1.4508**
TEMP	—	—	—
Number of observations	6429	1269	743
% predicted adoption	30.1	73.3	64.9
% correct predictions	75	75	69
Pseudo R^2 [1]	.43	.14	.15

** Significant at the 5-percent level.
* Significant at the 10-percent level.
[1] Veall and Zimmerman's pseudo R^2.

Note: For the table, the coefficients estimated from the limited dependent model have been converted into change in percent predicted adoption. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, RAIN AND TEMP), the reported value is the change in the percent predicted adoption given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in the percent predicted adoption between the values of 0 and 1. See Appendixes 2-A and 2-B for further details.

nitrogen will leach below the root zone. SLP had a positive and significant impact on the adoption of the combined modern practices and N-testing. This result, however, was realized only for N-testing in the single-area models.

A soil productivity index (PISOIL) was calculated to measure soil quality for crop growth. The index values range from 0 to 1, with higher values indicating more productive soils. Higher productivity soils have higher yields than those of lower quality, so the value of information (N-testing) is higher. The risk associated with not being able to apply nitrogen during the growing season is more costly for highly productive soils. For the combined-areas model, the productive capacity of soil (PISOIL) had a positive effect on N-testing adoption, but a negative influence on split nitrogen application use. Inherent erosion levels (EROTON) had no impact on the adoption of any of the modern practices.

Climate can play a major role in the need for nutrient management practices. Higher monthly average rainfall increases the potential for leaching and runoff of soil nutrients. We expected that in areas with elevated rainfall levels, agricultural producers would be more likely to adopt modern practices. Monthly temperatures were not expected to impact the adoption of modern practices. In the combined-areas model, average rainfall had a positive and significant influence on the adoption of the three modern practices and split nitrogen applications, whereas temperature had a positive effect only for split nitrogen application. That climate variables were significant for several single-area models supports the use of individual resource characteristics rather than just area dummies.

Table 3.9—Change in percent predicted adoption of manure use

Variables	Combined areas	Susquehanna River Basin
CONSTANT	0.7201**	-1.2068
COLLEGE	-0.0045	-0.1502*
EXPERIENCE	0.0009	0.0133
WORKOFF	-0.0026**	-0.0250*
TENURE	0.0224**	0.3006**
ACRES	-0.0115**	-0.1272**
ROW	0.0116**	0.1792**
SMGRAIN	-0.0013	0.1858**
DBL-CROP	-0.0072	—
IRRIGATION	0.0306**	—
ANIMAL	0.0537**	0.4781**
PROGRAM	-0.0031	0.0405
ADVICE	-0.0020	0.3237**
INSURE	0.0024	—
SLP	-0.0052	0.0673
PISOIL	0.0373**	0.1509
EROTON	0.0024*	-0.0284
RAIN	—	0.9591
TEMP	-0.2015**	—
Number of observations	6429	400
% predicted adoption	3.9	66.0
% correct predictions	91	77
Pseudo R^2 [1]	.36	.45

** Significant at the 5-percent level.
* Significant at the 10-percent level.
[1]Veall and Zimmerman's pseudo R^2.

Note: For the table, the coefficients estimated from the limited dependent model have been converted into change in percent predicted adoption. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, RAIN AND TEMP), the reported value is the change in the percent predicted adoption given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in the percent predicted adoption between the values of 0 and 1. See Appendixes 2-A and 2-B for further details.

"Traditional" Practices (Legumes in Rotation or Manure Use)

Long before commercial fertilizers became available, farmers were using legumes in rotation with other crops to provide nitrogen to soils. Even today, legumes are still the main source of fixed nitrogen for the majority of the world's soils. Adoption of legumes in rotation with grain crops has been a popular cropping practice because it allows farmers to reduce commercial nitrogen application on the succeeding crop. A rotation with legumes is a *traditional* nutrient management practice that offers economic and environmental benefits to producers and the public.

Farmers also have applied manure and other farm refuse to soils to replenish the soil nutrients removed by cultivated crops. Animal wastes are a source of organic nutrients and can be substituted for commercial fertilizers in crop production. Animal wastes can be an economical supply of nitrogen, phosphorus, potassium and other nutrients needed for crop production so long as there is a nearby source so that manure transportation costs are not high. Manure is not standard, however, but varies in its N-P-K content. The use of land application as a manure disposal option can also result in residual nutrients' being available for transport to the environment. The use of livestock manure does not indicate a more efficient use of nutrients necessarily, but does represent an organic rather than chemical source of nutrients.

The sample means for the combined-areas and single-area models are presented in table 3.3. The Illinois/Iowa and White River Basins areas were

selected for the single-area models of legume adoption, and the Susquehanna River Basin for manure use because these areas had a significant number of adopters. The model results, along with the significance levels, from the adoption studies are displayed in table 3.8 for legumes in rotation and in table 3.9 for the use of manure.

For the combined Area Studies sample, about 38 percent of producers used legumes in rotation. Tables 3.8 and 3.9 show that the predicted adoption of legumes in rotation for all areas combined was 30 percent, and predicted adoption for manure use was only 4 percent for the combined areas, but 66 percent for the Susquehanna River Basin (calculated at the sample means). The percent of correct predictions was 75 percent for the combined-areas legume model and 91 percent for manure use. The pseudo R^2 calculations were 0.43 and 0.36 respectively.

The human capital variables, EXPERIENCE, COLLEGE and WORKOFF, did not have much influence on the adoption of legumes in rotation as a nutrient management practice. The same result was obtained for the manure use model except for a negative effect for WORKOFF. Manure use is usually associated with livestock production which is very labor intensive and less likely to be chosen by producers who work off the farm. Farm ownership (TENURE) had a significant effect on adoption for both traditional practices for all models. Ownership had a positive influence on the use of manure and a negative effect on the use of legumes in rotation. Crop insurance (INSURE) had a negative and significant influence on adoption of legumes, but had no effect on manure use. Crop rotation may be the risk management strategy chosen by farmers to use instead of crop insurance.

Soil characteristics are important in explaining where legumes in rotation occur. Soil leaching potential (SLP) had a significant and negative effect on the adoption of legumes in rotation. The nutrient benefits of legume planting would dissipate in highly leachable soils. Manure use is not affected by SLP. For operations on which manure availability is not a limiting factor (i.e., manure disposal has a higher value to the producer than nutrient management), the reduction of nutrient leaching would not be considered as important to the individual decision maker. For the combined-areas models of legume adoption and manure use, the greater the productive capacity of the soil (PISOIL) the more likely the producers were using legumes in rotation. These results, however, do not hold for the single-areas models.

The amount of rainfall had no impact on adoption of legumes in the combined-areas model, but had a negative impact in the White River Basin. TEMP was significant and negative for manure use in the combined-areas model.

Summary

Although the results from the adoption models vary depending on the region and nutrient management practice examined, there were some general findings. As we expected, human capital had significant effects on the adoption of the more modern nutrient management technologies, which require a higher level of skill and management commitment than the more traditional technologies to use effectively. Working more days off-farm negatively affected the adoption of the modern practices and split nitrogen applications. An interesting result was that experience also negatively affected the adoption of modern practices and N-testing. Landownership had a negative and positive effect on the adoption of legumes in rotation and the use of manure, respectively. In addition, working more days off-farm reduced the probability of manure use. Crop insurance positively affected the adoption of modern practices and n-testing, although it had a negative impact on the adoption of legumes in rotation.

Farm size and cropping patterns also influenced the adoption of nutrient management technologies. Larger farm sizes increased the probability that a farmer would adopt modern practices or N-testing, indicating there may be economies of scale associated with larger farms. Smaller size farms were significantly more likely to adopt legumes in rotation and to use manure. Crop choice and irrigation were positive and significant determinants of all nutrient management practices in this study.

Resource characteristics helped explain the pattern of adoption for nutrient management practices. Producers with less sandy soils (measured by SLP) were more likely to adopt legumes in rotation, whereas those with more leachable sandy soils were more likely to adopt modern practices and N-testing. An interesting result was that those with highly productive soils as measured by the PISOIL index were more likely to adopt N-testing and the traditional nutrient management technologies of legumes in rotation and manure use only in the combined-areas models; these effects were not significant in the individual area models. Farmers with less productive soils were more likely to adopt split nitrogen applications. The use of a general productivity index may mask the importance of certain

individual soil characteristics such as organic composition. In a region-specific model, it may be best to identify resource characteristics known to be important in the area.

Climate had varying effects on the adoption of nutrient management practices. In some places, higher average monthly rainfall and temperature were associated with the adoption of some of the *modern* nutrient management technologies. In contrast, lower average monthly temperature was associated with the adoption of manure use, a *traditional* nutrient management technology.

A significant factor in the adoption of all of the *modern* nutrient management technology models was receiving some outside information on nitrogen fertilizer applications. This result was strong and positive in all cases, indicating that the outside information encourages farmers to adopt *modern* nutrient management technologies. Advice was less important for the adoption of traditional practices, with the exception of manure use in the Susquehanna River Basin.

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4. Pest Management

In this chapter, we briefly describe pest management issues and the technologies and practices designed to reduce risks to human health and the environment. The Area Studies survey data are described with respect to the use of specific practices. The results of simple adoption models for these practices are reported for the combined-areas and single-area models, and the factors affecting the adoption of pest management practices are described. The modeling framework and the core set of variables used in these analyses are described in chapter 2.

Pests are defined as weeds, insects, nematodes, fungi, or any living organism that is undesirable or hazardous to a crop. Damage to crops by pests can result in reductions in yield, quality, or both. The severity of a pest problem is influenced by many factors including rainfall, humidity, wind patterns, soil type, and other growing conditions. The relative effectiveness of pest management strategies will vary as a function of these factors.

Summary of Pest Management Practices and Data

There are two main pest management categories: *chemical control methods* and *nonchemical control methods*. The use of chemical controls has been the dominant form of pest management since the 1950's (Osteen and Szmedra, 1989). The use of pesticides has produced high yields, and pesticides are relatively easy to apply. More than $7 billion per year is spent in the United States on agricultural pesticides (USDA, ERS, 1996). Recently, however, alternative, nonchemical pest management strategies and services have been promoted as a result of concerns about pesticide exposure effects on human health and environmental quality (U.S. EPA, 1990, 1992; Barbash and Resek, 1995). There is also a concern that the widespread use of chemical pesticides has led to an acceleration of pest resistance to those chemicals (Padgitt, 1997). Greene (1997) gives an excellent summary of current pest management issues.

The potential risk of pesticide use to human health or the environment depends on the toxicity and persistence of the chemical, the availability of residuals, and the mechanism of transport. These factors are functions of the characteristics of the chemicals, the practices used, and the physical properties of the land. The environmental-impact characteristics of the natural resource base are an important determinant of potential damages. The relative effectiveness of alternative pest management strategies for sustaining profitability and reducing damages will be site specific (Caswell and Shoemaker, 1993). The Area Studies survey was designed to collect data on both the chemical and nonchemical control methods employed. Data were also collected on other farm management practices and the production-impact and environmental-impact characteristics of the field.

A farmer's decision to adopt a particular pest management strategy will be based on his or her assessment of the increase in net benefits to be gained by a change in practice. The assessment would include costs, yields, and on-site health or environmental risks. The decision would not be expected to include off-site benefits that would accrue to others.

Chemical Pest Management

The three major classes of chemical pesticides are insecticides, herbicides, and fungicides. Insecticides are used to destroy or control insects. Herbicides are used to control weeds or unwanted vegetation. They can be applied either before or after emergence of the weeds. Fungicides are used to kill or inhibit the growth of fungi that cause disease in plants or seeds. Pesticides other than insecticides, herbicides, or fungicides can be classified as miscellaneous chemicals, such as defoliants or desiccants, soil fumigants, and growth regulators.

Pesticide usage varies greatly by crop. In the Area Studies survey data, for instance, insecticides were applied to almost 64 percent of the cotton acres planted, but to only 3 percent of the wheat acreage. This is due to the specific nature of the pest problems associated with each crop. For example, cotton is often plagued by the boll weevil; corn is susceptible to corn rootworm damage; and potatoes may require fungicides to treat early and late blight. See table 4.1 for a summary of the distribution of pesticide usage in the Area Studies data by pesticide class and by crop.

The amount of active ingredient (*ai*)—the active chemical in a formulation of pesticide—also varies substantially by crop. Corn growers apply 0.7 pounds *ai* of insecticide per acre, whereas cotton growers apply more than double this amount—1.88 pounds *ai* per

acre. Figure 4.1 shows the distribution of the pounds of active ingredient applied on a per acre basis by pesticide class and crop. Regional differences in pounds applied of pesticides reflect local growing and economic conditions. Figures 4.2 and 4.3 show some of the regional differences in the pounds of *ai* applied of insecticides and herbicides. The pounds of *ai* of herbicides applied on cotton, for instance, in the Southern High Plains is 1.15, but rises to 3.1 in the Mississippi Embayment. There is much less variation, on the other hand, in the amounts of herbicides applied to soybeans—which ranges from a low of 0.90 pounds of *ai* in the Southern Georgia Coastal Plain to a high of 1.36 in the Albemarle-Pamlico region.

Nonchemical Pest Management Practices and Services

Farmers often use nonchemical pest management practices and services in conjunction with, or as a supplement to, traditional chemical control methods. Some of these practices are used only on specific crops. For instance, pruning and canopy management is often used for tree crops, but rarely for any other crops. The specific mix of practices a farmer chooses often depends on the crop grown, the type of pest, and the extent of the pest problem. The box on page 50 provides definitions of some of the more common nonchemical pest management practices covered in the Area Studies survey, and table 4.2 presents the adoption rates of each of these practices within the Area Studies survey area.

The USDA and EPA have initiated programs to encourage the use of integrated pest management (IPM) strategies as a means of reducing pesticide use and risks. IPM is a systems approach to pest management that combines a wide array of crop production practices with careful monitoring of pests and their natural enemies (Lynch et al., 1997). Pest treatments are prescribed when pest populations reach a threshold level above which economic damage to the crop would occur. An IPM strategy may include the application of synthetic chemicals in combination with cultural and biological practices. The USDA and EPA goal has been to promote the use of ecologically based pest management approaches that reduce the risks to health and the environment associated with the use of synthetic chemical pest controls while ensuring the economic viability of providing a safe, affordable, and plentiful supply of agricultural products (Lynch et al., 1997). Because IPM can encompass several different strategies at once and because there is no consensus on a single definition for IPM, we refer to nonchemical control methods individually in our analysis.

Many of the nonchemical methods for pest control are not widely used. In the Area Studies survey, for

Table 4.1—Crop acres receiving pesticide applications—combined areas

	Corn	Cotton	Potatoes	Soybeans	Wheat
			Percent		
Insecticides	30.1	63.5	65.2	3.9	2.9
Herbicides	90.8	94.8	76.3	92.7	36.2
Fungicides	0.1	12.5	35.5	0.5	0.9
Other	0.3	64.9	15.7	0.5	0.2

Figure 4.1
Average pounds of active ingredient applied per acre, by crop

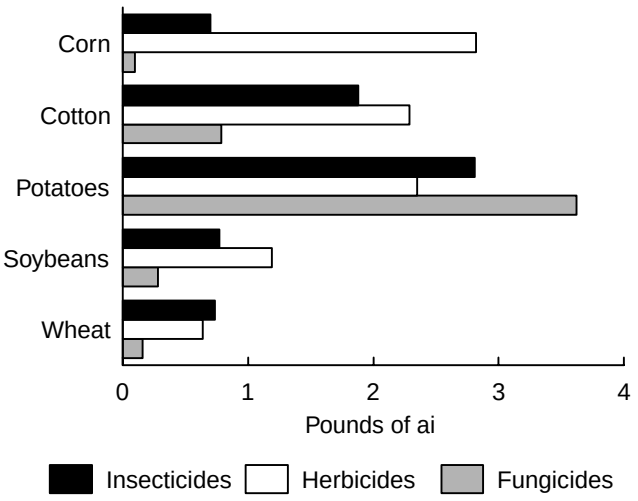
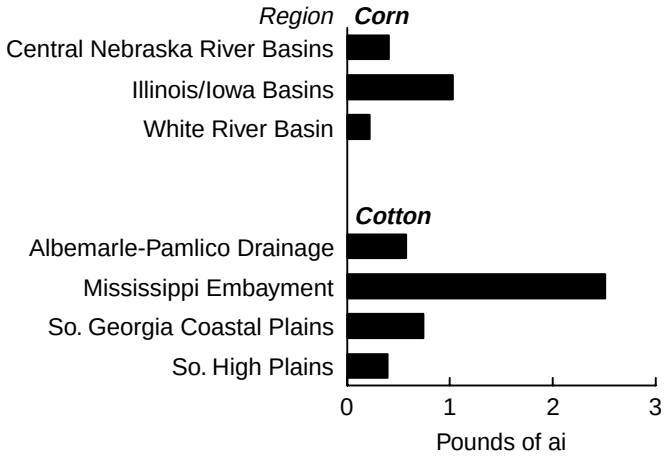


Figure 4.2
Pounds of insecticide applied per acre, by region and crop



instance, roughly 3 percent of the crop acreage reported using any biological controls (table 4.2). The most prevalent method employed was crop rotations, although the primary reason for using this technique is not for pest management. In addition to crop rotations, some of the more commonly used practices include destroying crop residues, planting pest-resistant varieties, using strategic locations and planting times, and professional scouting. Professional scouting can entail the identification of pests in the field, an assessment of the extent of infestation, and recommendations about the chemical or nonchemical pest management strategies to use. The use of scouting has been promoted based on the assumption that it will lead to a more efficient strategy than the use of a fixed schedule of chemical pesticide applications. The adoption of scouting has not been associated with reduced chemical use in all cases, however (Ferguson and Yee, 1995; Fernandez-Cornejo, 1996). Mitra (1997) found that access to information could increase aggregate toxicity or aggregate expenditures of chemicals. These results imply that an increase in economic efficiency does not necessarily lead to an improved environmental outcome.

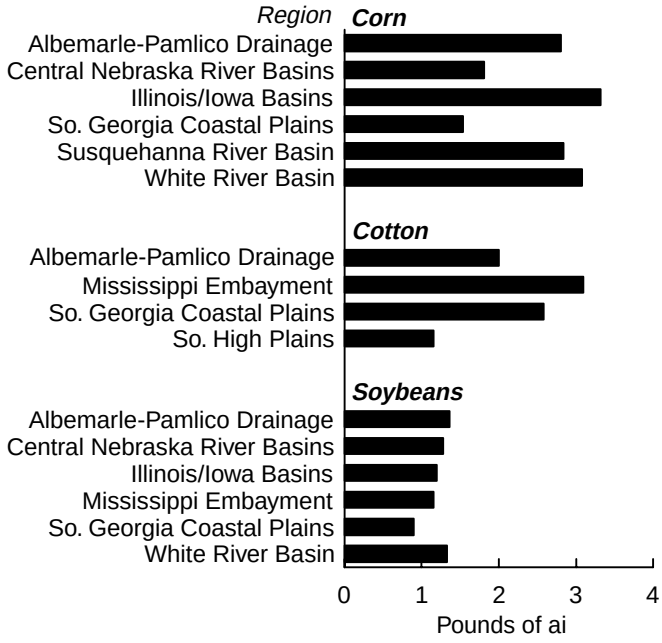
Farmers often rely on outside sources of information that report pest infestation levels in the area and also give advice on best to control the pests. The farmer may hire someone to aid in the job of pest control. This staff member would be professionally trained in entomology or considered to be a pest management expert. Other sources of information include the pest management services provided by an employee of the Extension Service, university, or State, Federal, or other government agency. Farmers also often receive the advice of professional pest scouts provided by a chemical dealer, supplier, or store as a part of the business' service. Finally, farmers can hire professional scouts to monitor the presence of various types of pests in their fields and to assess the benefits of pest management strategies. A distribution of the percentage of farms using particular sources of advice by crop is presented in figure 4.4. Some farmers, of course, do not receive advice from any of these sources. In general, though, we would expect farmers who receive some form of information or advice to be more aware of the various pest control strategies and alternatives that are available to them when making their pest management decisions. For purposes of the pest management adoption models, a variable was created (ADVICE) to indicate whether farmers had used any of the following for pest management: professional scouts; hired staff; local extension service, university, or State or Federal agencies; or chemical dealers, suppliers, or stores to test the hypothesis that farmers who sought information were more likely to adopt nonchemical strategies.

Adoption rates for nonchemical pest management strategies can vary greatly depending on the crop grown. Fifty-three percent of cotton acres were professionally scouted versus only 10 percent of corn acres. Some of the variation in adoption rates between crops can be explained by the specific nature of the pest problems associated with each crop. Dummy variables for certain crops or crop groups (CORN, COTTON, SOYBEANS, GRAIN, FRTVEG) were used in the analyses to capture the effect of crop choice on pest management adoption. Figure 4.5 shows the distribution of the level of adoption for selected practices by crop.

Table 4.2—Adoption of pest management practices—combined areas

Pest management practice	Percent of acres
Biological pest controls	3.2
Crop rotations	53.9
Crop residue destruction	26.1
Nonpesticide sprays	1.8
Pest-resistant varieties	20.4
Pheromones	3.4
Professional scouting	14.9
Pruning and canopy management	2.7
Strategic locations and planting times	12.4

Figure 4.3
Pounds of herbicide applied per acre, by region and crop



Regional differences were also important. In the Southern Georgia Coastal Plain, crop residue destruction is used on 71.9 percent of the cropland as a pest management strategy, compared with only 4.5 percent of cropland acres in the Central Nebraska River Basins. The warm, moist climate in the Georgia area makes it more prone to insect infestations, and therefore makes crop residue destruction a more effective pest management strategy than in the Central Nebraska Basins. Table 4.3 and figures 4.6-4.9 show the distributions of adoption levels by region for each of the four chosen nonchemical practices. Biological controls and pheromones are grouped together since they are similar practices in that they both use natural means of disrupting the pest cycle.

In general, we did not expect natural resource assets on the farm to have much influence on a farmer's decision to adopt particular pest management strategies except for those practices that also contributed to other sources of increased productivity. For example, crop rotations can be used both to break pest cycles and to add nutrients for crop growth. Soil type may influence the decision to use rotations for nutrient management and not pest management. Soil characteristics may not be a factor in the decision to use pheromones. For comparison with the models for soil, nutrient, and water management practices, however, we included the soil leaching potential (SLP) and productivity (PISOIL) core variables in the pest management analyses. Climate was expected to have a strong influence on the choice of pest management practices. Warm, moist weather and mild winters contribute to increases in pest populations.

Adoption of Pest Management Practices

To investigate which factors affected the adoption of nonchemical pest management practices, four models of pest management adoption were selected: (1) rotations; (2) crop residue destruction; (3) biological controls and pheromones; and (4) professional scouting. These particular practices were chosen because they have relatively high adoption rates and they provide the best insight into the human capital, cropping practice, and natural resource factors affecting adoption. In general, these models can be thought of as two distinct categories of technologies—traditional and modern. The use of crop rotations and the destruction of crop residues were well established before the introduction of chemical pest-control strategies. On the other hand, biological controls, pheromones, and professional scouting represent more recent and modern approaches to controlling pests.

First, the adoption model that includes all 10 of the Area Studies regions combined will be discussed (referred to as the "combined-areas" model), and then the results from selected single areas will be reviewed briefly. Selected single-area models were analyzed to test for the effects of regional heterogeneity on the choices of pest management strategies. The analysis

Figure 4.4
Pest management advice by crop

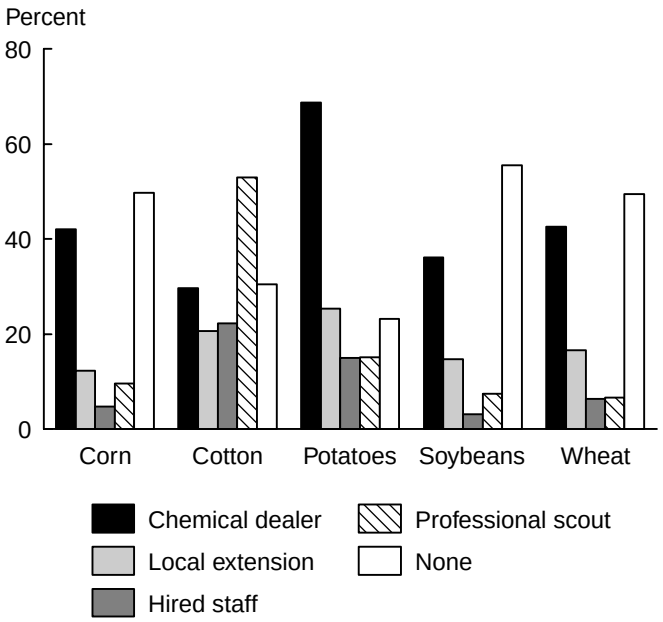
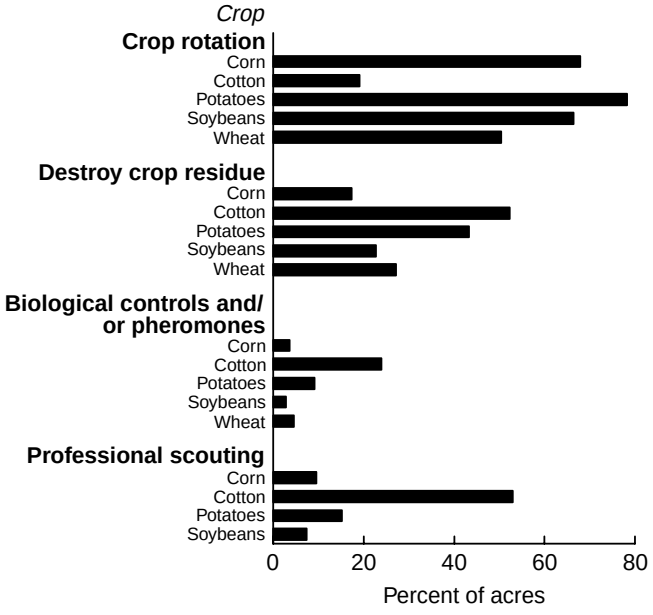


Figure 4.5
Pest management practices by crop



framework and the core set of variables are explained in depth in chapter 2.

Crop Rotations

The sample means for the combined-areas and single-area models are presented in table 4.3. The regions chosen for the single-area adoption models include 8 of the 10 areas; the Central Nebraska, Illinois/Iowa, White, and Snake River Basins, the Southern Georgia Coastal Plain, Southern High Plains, Mississippi Embayment, and Albemarle-Pamlico Drainage areas. The Mid-Columbia and Susquehanna River Basins were not included in the empirical analysis. The empirical results from the adoption study of crop rotations are displayed in table 4.4.

In the combined-areas model, about 54 percent of producers in the sample used crop rotations. Table 4.4 shows that the predicted probability of adopting crop rotations for all areas combined was 0.547 calculated at the sample means. The percent correct predictions was 75 percent and the pseudo R^2 was 0.46.

The human capital variables, COLLEGE, EXPERIENCE, WORKOFF, and TENURE were not statistically significant for the adoption of crop rotations for either the combined- or single-area models. This result may not be surprising given that crop rotations are considered to be a traditional pest management technology that does not require a high level of management expertise or large financial investment. The effect of tenure on the adoption of rotations was negative and significant only in the Southern Georgia model indicating that owners in that area were less likely to adopt crop rotations than renters. Only in Albemarle-Pamlico and Southern Georgia were farmers who had crop insurance more likely to adopt crop rotations.

The number of acres operated had no effect on the adoption of crop rotations in the combined-areas model. In the Albemarle-Pamlico, Snake River, and White River areas, the larger the number of acres operated, the higher the probability of adoption of crop rotations. In the Central Nebraska River Basins, however, the number of acres operated had a negative effect on adoption. A stratified sample shows that the average acres operated for a corn grower in Central

Table 4.3—Sample means from pest management adoption models by area

Variables	Combined areas	Albemarle-Pamlico	Central Nebraska	Illinois/Iowa River Basins	Mississippi Embayment	Snake River Basin	Southern Georgia	Southern High Plains	White River Basin
ROTATIONS	.54	.74	.42	.82	.27	.66	.71	.19	.78
DESTROY RESIDUE	.26	.54	.05	.08	.37	.36	.72	.37	.23
BIOLOGICAL	.06	.13	.04	.02	.11	.04	.17	.04	.01
SCOUTING	.15	.12	.14	.04	.30	.08	.18	.22	.03
COLLEGE	.44	.34	.38	.38	.47	.60	.39	.54	.42
EXPERIENCE	24	25	24	25	23	21	25	23	25
WORKOFF	32	33	30	41	21	35	42	24	64
TENURE	.38	.34	.43	.38	.30	.62	.47	.36	.40
ACRES	1703	1735	1624	910	2332	2550	1499	1972	931
CORN	.30	.28	.50	.57	.07	.01	.26	.07	.51
COTTON	.15	.11	0	0	.30	0	.15	.60	0
SOYBEANS	.31	.33	.23	.43	.49	0	.19	0	.42
GRAIN	.22	.28	.25	.09	.11	.72	.17	.27	.11
DBL-CROP	.06	.16	.01	.02	.08	0	.11	.06	.02
IRRIGATION	.26	.08	.41	.02	.39	.81	.26	.45	0
PROGRAM	.80	.77	.74	.85	.87	.47	.80	.92	.68
ADVICE	.44	.45	.27	.56	.37	.62	.53	.35	.31
INSURE	.40	.26	.42	.63	.14	.27	.32	.70	.18
SLP	119	121	125	91	116	150	148	151	112
PISOIL	.80	.53	.84	.94	.80	.82	.37	.69	.90
RAIN	3.1	4.0	2.1	3.0	4.3	1.2	4.1	1.6	3.4
TEMP	55	60	49	50	61	44	65	58	52
Number of observations	6574	769	709	1276	822	537	511	508	779

Refer to table 2.2 for variable definitions and units.

Figure 4.6
Adoption of crop rotation by region

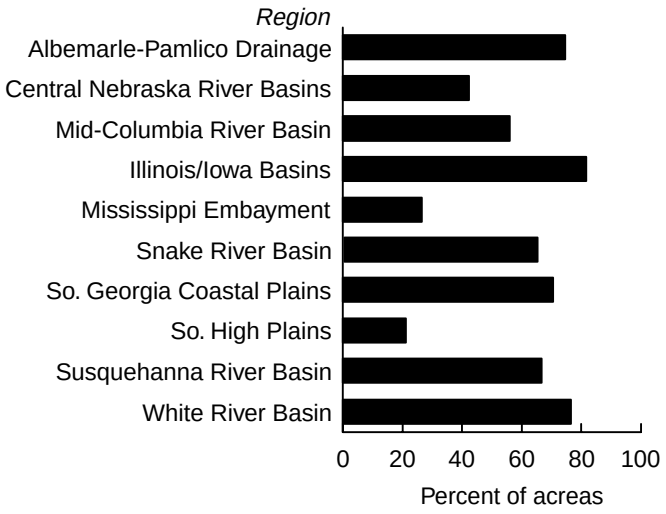


Figure 4.7
Adoption of crop residue destruction by region

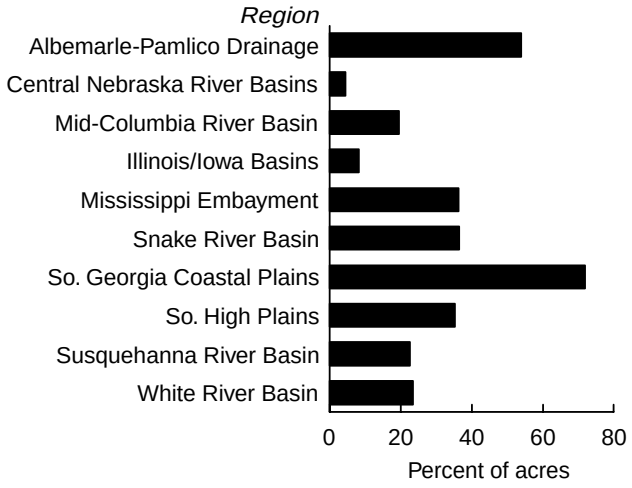


Figure 4.8
Adoption of biological controls and pheromones by region

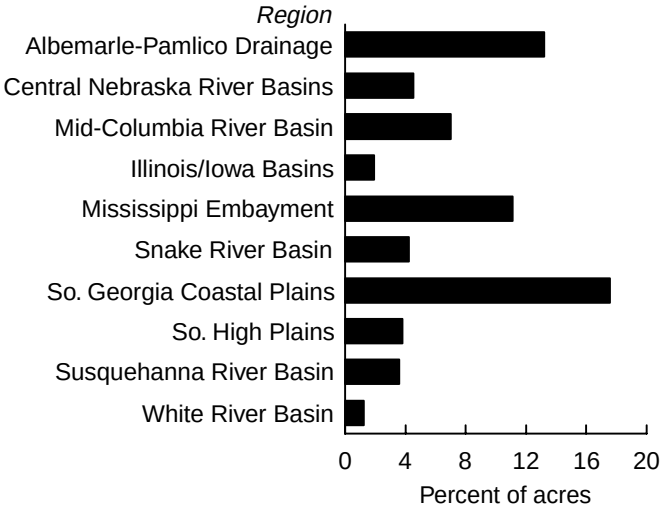
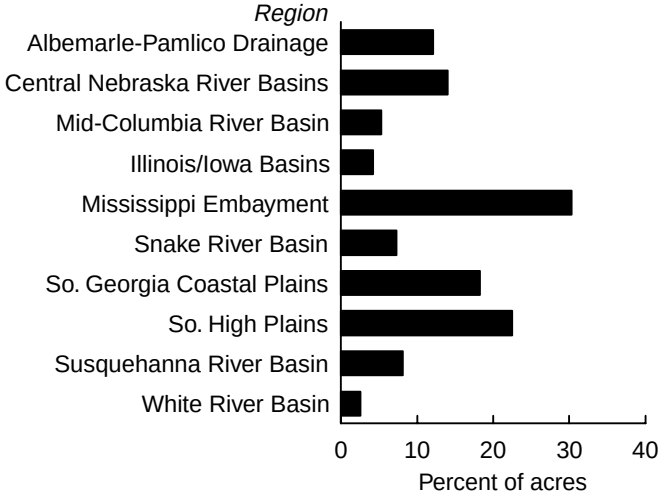


Figure 4.9
Adoption of professional scouting by region



Nebraska was 1,146, whereas the average acres operated for farmers who did not grow corn was 2,103. Because corn is one of the dominant crops in Central Nebraska, this might explain why there is a negative relationship between farm size and adoption. Regional differences were obscured when the areas were combined. Farm size does not appear to have any cost or information advantages with respect to the adoption of crop rotations.

Dummy variables for soybeans and grains and hays were included in the combined-areas model.[1]

Soybeans (SOY) were produced by 31 percent of farmers and grains and hay crops (GRAIN) were produced by 22 percent of the farmers. Grains were defined as either wheat, barley, oats, rye, alfalfa, or other hay. As expected, farmers who grew soybeans were significantly more likely to be rotating crops than farmers who grew other crops for the combined-areas model and four of the single areas. In the Snake River and Southern High Plains areas, soybeans were not produced, so dummy variables for row crops (corn, soybeans, cotton, tobacco, potatoes, or sorghum) and cotton were used respectively. The partial effects in both cases were negative and significant. Similarly, farmers growing grains and hays were significantly less likely to adopt crop rotations.

[1] Since some agricultural producers cultivated both soybeans and grains in their fields, each crop dummy variable can be considered apart from the other in the combined-areas adoption models.

Double-cropping increased the probability of adopting crop rotations. Farmers may double-crop in order to control for pests and natural enemies that overwinter in the soil or crop residue, and therefore they may be more likely to adopt rotations as part of their pest management strategy. It should be pointed out, however, that the results for double-cropping are driven primarily by a single area, Albemarle-Pamlico.

The use of irrigation had an overall positive and significant effect on the adoption of crop rotations in the combined-areas model and in the Albemarle-Pamlico, Mississippi Embayment, and Southern High Plains models. The use of irrigation had a negative effect on the adoption of rotations in the Corn Belt. This result reflects some regional variations and may be indicative of the fact that some irrigated crops may be more prone to pest infestations and, therefore, more likely to be rotated. Planned rotations can also aid in conserving soil moisture, so farmers who have a need to irrigate may be using rotations to conserve soil moisture in regions with low rainfall.

Farmers were asked whether or not their operation was enrolled in a farm program (e.g., price supports, crop quotas, or the CRP). Farmers who received farm program benefits were significantly more likely to adopt crop rotations than those who did not in the combined-areas model and in Albemarle-Pamlico, Southern Georgia, and White River areas. This result is somewhat surprising since the 1985 Farm Bill, which was in effect during the Area Studies survey period, stated that planting a nonprogram crop on base acres would result in the loss of commodity program eligibility.

Table 4.4—Change in the percent predicted adoption of rotations

Variables	Combined areas	Albemarle-Pamlico	Central Nebraska	Illinois/Iowa River Basins	Mississippi Embayment	Snake River Basin	Southern Georgia	Southern High Plains	White River Basin
CONSTANT	-1.0790	-1.6367**	-0.3787	-1.8514**	6.4122**	-0.4948	2.5563	-0.7896	1.9604**
COLLEGE	0.0044	0.0373	-0.0692	0.0066	-0.0221	-0.0621	0.0485	0.0107	0.0236
EXPERIENCE	0.0054	-0.0261	0.0121	-0.0302	-0.0075	0.0377	-0.0017	0.0371	-0.0089
WORKOFF	-0.0038	-0.0120*	-0.0109	-0.0065	0.0048	0.0026	-0.0070	0.0035	0.0091
TENURE	-0.0297*	-0.0239	-0.0830*	-0.0326	0.0444	0.0226	-0.1162**	0.0500	-0.0513*
ACRES	0.0062	0.0405**	-0.0529**	0.0026	0.0192	0.0851**	0.0066	0.0272	0.0328**
SOYBEANS	0.2574**	0.0031	0.2926**	0.1538**	0.1862**	-0.3521**[1]	0.1449**[1]	-0.1647**[2]	0.1235**
GRAIN	-0.1325**	-0.0852*	-0.0983	-0.0506*	0.1010	-0.4667**	-0.1386**	-0.1815**	-0.1515**
DBL-CROP	0.1146**	0.1510**	—	—	-0.0122	—	0.1044	0.1127	0.2079
IRRIGATION	0.1371**	0.1539**	-0.1568**	-0.1763**	0.2556**	0.1256*	0.0795	0.1773**	—
PROGRAM	0.0767**	0.1111**	-0.0204	-0.0233	0.0694	-0.0420	0.2279**	0.1596*	0.0757**
ADVICE	0.1739**	0.0691**	0.0718	0.0472**	0.2291**	0.1626**	0.1431**	0.0657**	0.0257
INSURE	0.0025	0.1469**	0.0175	0.0225	-0.0550	0.0657	0.2649**	0.0037	0.0695*
SLP	-0.2320**	-0.0078	-0.0550	-0.2063**	-0.1368*	0.0898	-0.1823	0.1376	-0.0835
PISOIL	0.2365**	-0.1108	0.3152**	-0.1804*	0.1971**	0.2062**	0.0934	0.1492**	-0.3275**
RAIN	-0.0497	1.1337**	0.5863**	—	—	-0.3923**	-0.1089	—	-1.3258**
TEMP	0.3045	—	—	0.6166**	-1.7444**	—	-0.6088	-0.0212	—
Number of observations	6574	769	709	1276	822	537	511	508	779
% predicted adoption	54.7	78.7	39.1	86.2	21.8	70.6	76.1	13.3	81.5
% correct predictions	75.3	79.6	71.7	84.2	80.9	73.9	76.5	82.9	80.9
Pseudo R^2 [3]	.46	.36	.36	.22	.33	.29	.37	.33	.28

— Variable not included in the adoption model.
** Significant at the 5-percent level.
* Significant at the 10-percent level.
[1] Rowcrop
[2] Cotton
[3] Veall and Zimmerman's pseudo R^2.

Note: For the table, the coefficients estimated from the limited dependent model have been converted into change in percent predicted adoption. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, RAIN AND TEMP), the reported value is the change in the percent predicted adoption given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in the percent predicted adoption with a unit change of 0.01 from the variable mean. See Appendixes 2-A and 2-B for further details.

Receiving some form of pest management information or advice (ADVICE) was positively and significantly related to use of crop rotations in all models except in the Central Nebraska and White River Basins. Table 4.5 shows that 64.2 percent of agricultural producers who sought out pest management advice used crop rotations, versus 47.1 percent of producers who did not seek advice. The technical assistance and advice farmers received appears to have encouraged them to adopt crop rotations. However, it is also possible that farmers who sought advice were already prone to pest or weed problems. They may have been more likely to adopt a pest management strategy like crop rotations because of a current infestation and not necessarily because they received advice.

Soil characteristics are important in explaining where farmers tend to use crop rotations. SLP had a significant and negative impact on the adoption of crop rotations. In other words, producers with sandier soils were less likely to adopt crop rotations. This result, however, is driven by a single area, the Illinois/Iowa River Basins. For the combined-areas model and three single areas, the greater the productive capacity of the soil, the more likely were producers to use crop rotations. On the other hand, producers with more productive soils in the White River Basin were less likely to adopt crop rotations. The resource characteristics combined within the PISOIL index may not be capturing the production-impact characteristics that are important in individual areas. The use of crop rotations is a nutrient management strategy as well as a pest control strategy.

Table 4.5—Percent predicted adoption—combined areas

Variables	Rotations	Destroying crop residues	Professional scouting	Biological controls
College		*	*	*
Yes	55.0	17.1	10.2	3.8
No	54.5	22.3	6.7	2.4
Land tenure			*	
Yes	52.9	20.1	7.1	3.2
No	55.8	19.8	8.8	2.8
Land operated			*	*
500 acres	54.3	20.2	6.2	2.6
5,000 acres	55.7	19.2	15.4	4.0
Cotton	*1	*	*	*
Yes	71.2	32.6	42.6	22.5
No	46.6	18.1	5.7	2.0
Use irrigation	*	*	*	*
Yes	64.5	22.8	16.6	3.9
No	51.1	19.0	6.2	2.7
Received advice	*	*	*	*
Yes	64.2	25.7	12.0	4.8
No	47.1	16.2	5.9	2.0
Percent adoption at means	54.7	19.9	8.1	3.0

* Significant at the 5-percent level.
1 Soybeans, not cotton.

Climate can play a major role in the need for pest management practices. Higher monthly average rainfall and higher monthly temperatures can be proxies for humidity levels and the potential for pest outbreaks. Warmer climates also often have more types of pests. It would be expected that producers in hot, humid regions would be more likely to adopt pest management strategies and practices as a means of controlling pest infestations. Average rainfall and temperature did not significantly influence the farmer's decision to use crop rotations in the combined-areas model, but they did influence the use of crop rotation in all single-area models, except Southern Georgia and the Southern High Plains.[2] In Albemarle-Pamlico and Central Nebraska, rainfall had a positive effect, and temperature had a positive effect in the Illinois/Iowa Basins. In these areas, a warmer or more humid climate appears to encourage the adoption of rotations as a possible pest management strategy. However, in the Mississippi Embayment, temperature had a negative effect, and rainfall had a negative influence in the Snake and White River Basins. The results from the single-area adoption models provide evidence that climate is selectively important in how it affects use of crop rotation and climate's importance varies substantially in its effect across regions.

Crop Residue Destruction for Pest Management

Like crop rotations, destruction of residues is considered to be another traditional pest management strategy (see box, p. 50). Therefore, we expected that some of the same factors that affect the use of rotations to affect the use of this technology. However, from a whole-farm perspective, crop residue destruction may not be the best pest management strategy, particularly for farmers with soil erosion problems.

[2] The temperature and rainfall variables in the single-area adoption models were so highly correlated, we retained only one variable in each region, the choice depending on variation and model fit.

The sample means for the combined-areas and single-area models are presented in table 4.3, which shows that about 26 percent of farmers in the entire sample practiced crop residue destruction for pest management. A stratified sample statistic indicated that these farmers had soil with a lower-than-average inherent potential to erode due to rainfall and wind. For the combined sample, the average potential soil erosion rate was 35 tons per acre per year, whereas the erosion rate for farmers who destroyed crop residue was only 26 tons per acre per year.

The model results from the adoption study of crop residue destruction are displayed in table 4.6. The predicted probability of the adoption of crop residue destruction for the combined-areas model at the sample means was 0.199. The percent correct predictions was 77 percent and the pseudo R^2 was 0.37. The single-area adoption models cover three regions: Albemarle-Pamlico, Mississippi Embayment, and Southern Georgia. These areas were chosen because they had the largest individual adoption rates for crop residue destruction. The proportion of farmers who destroyed crop residues was 54 percent in Albemarle-Pamlico, 37 percent in the Mississippi Embayment, and 72 percent in Southern Georgia (table 4.3).

For the combined-areas and Albemarle-Pamlico models, COLLEGE and EXPERIENCE had a negative and significant association with crop residue destruction. Table 4.5 shows that for the combined-areas model, the predicted adoption for farmers with some

Table 4.6—Change in the percent predicted adoption of crop residue destruction for pest management

Variables	Combined areas	Albemarle-Pamlico	Mississippi Embayment	Southern Georgia
CONSTANT	-2.9584**	-13.307**	-2.5266	4.1624
COLLEGE	-0.0528**	-0.1787**	-0.1237**	-0.0670
EXPERIENCE	-0.0326**	-0.1214**	-0.0514	0.0184
WORKOFF	0.0042*	-0.0012	0.0111*	-0.0089
TENURE	0.0024	-0.0148	0.0476	-0.1107**
ACRES	-0.0043	0.0377*	0.0097	-0.0165
COTTON	0.1249**	0.2444**[1]	0.2638**	0.1955**
GRAIN	-0.0669**	-0.1014	—	-0.2565**
DBL-CROP	-0.0103	-0.1038	-0.1022	0.1674**
IRRIGATION	0.0367**	-0.0208	0.1031**	0.0646
PROGRAM	0.0154	0.2475**	0.0756	0.2194**
ADVICE	0.0934**	0.0623	0.1958**	0.1225**
INSURE	-0.0019	-0.0004	-0.0387	0.1999**
SLP	-0.0070	0.0513	-0.0668	0.2789
PISOIL	0.0340	-0.0072	0.0170	0.2385**
EROTON	-0.0259**	-0.0955**	-0.0086	0.0098
RAIN	0.1892**	—	—	-0.5117
TEMP	0.6468**	3.2113**	0.5394	-0.9322
Number of observations	6574	769	822	511
% predicted adoption	19.9	53.1	34.9	77.5
% correct predictions	77.4	69.7	73.8	77.7
Pseudo R^2 [2]	.37	.34	.23	.38

— Variable not included in the adoption model.
** Significant at the 5-percent level.
* Significant at the 10-percent level.
[1] Tobacco
[2] Veall and Zimmerman's pseudo R^2.

Note: For the table, the coefficients estimated from the limited dependent model have been converted into change in percent predicted adoption. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, RAIN AND TEMP), the reported value is the change in the percent predicted adoption given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in the percent predicted adoption with a unit change of 0.01 from the variable mean. See Appendixes 2-A and 2-B for further details.

college education is 17.1 percent compared with 22.3 percent for farmers without any college education. Education also had a negative impact on adoption in the Mississippi Embayment area. Farm ownership (TENURE) had no effect on crop residue destruction except in the Southern Georgia model for which it had a negative effect. The use of insurance had a positive effect on adoption in the Southern Georgia model. In general, the human capital effects were stronger for crop residue destruction than for crop rotations.

Farm size was not a significant influence on adoption in any of the models. Crop choices were significantly associated with crop residue destruction. In all models, the choice of cotton as a crop had a positive impact on adoption. Cotton was produced by 15 percent of all the farmers in the combined-areas model. In a stratified sample, 53 percent of cotton growers destroyed crop residues as a pest management technology, compared with 22 percent of producers who did not grow cotton. Because cotton is often produced in

Glossary of Nonchemical Pest Management Practices

Biological pest controls — the use of beneficial insects or natural enemies, such as praying mantises and ladybugs, which are collected and introduced into locations because of their value in biologic control. These insects prey on other harmful insects and parasites. Biological pest control also includes the use of trap crops. A trap crop is any crop planted to attract or divert insects or other pests away from the primary host crop. Other examples of biological pest controls are microbial agents, cover crops, and mulching.

Crop rotations — the practice of successively growing different crops on the same piece of land over a span of 2 or more years in order to combat pests. Crop rotations are used primarily to improve or maintain soil productivity, but have the secondary benefit of breaking up the pest life cycle. Rotations provide, in many situations, a cheap and effective means of control.

Crop residue destruction — helps to provide a host-free zone. Host-free zones are areas in which the natural or preferred habitat for a pest has been removed or destroyed so that the pest's breeding patterns are disturbed. Destroying crop residue can also alter a habitat by producing changes in the physical environment, i.e., by modifying the soil texture, moisture, temperature, and other characteristics that may affect a pest's ability to survive.

Nonpesticide sprays — nonchemical solutions used to control pests. These sprays include lime water, insecticidal soaps, and elemental and organic compounds used for pest control.

Pest-resistant varieties — crop plants with known resistance to one or more pests. Host-plant resistance is often the result of breeding plants to enhance genetic properties that make them less susceptible to pest damage or disease or to interrupt the normal host-selection process.

Pheromones — chemical sex attractants which can be used to capture insects for measuring population counts or to reduce populations by disrupting mating. The use of pheromones for monitoring pests enables farmers to accurately determine the size of the population and the rate at which it is growing. Pheromones are insect specific and are not available or do not exist for all insect types.

Professional scouting — monitoring the presence and population counts of various types of pests in the field by taking samples. These samples are taken by entomologists or other professionally trained specialists, and are reported to the grower. The population counts or scouting reports are then used to schedule pesticide applications only when a pest population has reached a point that threatens the profitability of the crop.

Pruning and canopy management — pruning and leaf removal done to control pests or diseases. Although removing infested or diseased twigs may reduce the spread of infestation, it can be labor intensive.

Strategic locations and planting times — another means of keeping pests off the crop grown in a particular field. By selecting planting sites on a farm where insects may not exist or exist in fewer numbers, or by manipulating planting dates, a farmer may exercise some control over potential pest infestations. Planting dissimilar crops adjacent to one another may also be a means of keeping pests off the primary crop if the other crop is useful at attracting pests away from the primary crop.

warm, humid areas it may be more prone to pest infestations. Grain crops, on the other hand, were negatively associated with the adoption of crop residue destruction in the combined-areas and the Southern Georgia models.

Producers who irrigated were positively and significantly associated with crop residue destruction for the combined-areas and Mississippi Embayment models. The Mississippi Embayment area had the highest average monthly rainfall, 4.3 inches, of all the regions and had a substantial amount, 39 percent, of irrigation (see table 4.3). Farmers who irrigate in this region may have more severe pest problems than farmers who do not.

Participating in a government program had no impact in the combined-areas model, but had a significant positive influence in the Albemarle-Pamlico and Southern Georgia models. Producers who received some form of information or advice from hired staff, extension service, or chemical dealers were more likely to destroy crop residues as a pest management practice than those who did not receive any advice for all single-area models except Albemarle-Pamlico.

In general, the natural resource variables defining soil quality, SLP and PISOIL, did not significantly affect a farmer's use of crop residue destruction. The coefficient for PISOIL in the Southern Georgia model was positive and significant. The inherent potential of the soil to erode (EROTON) had a significant and negative influence on adoption for the combined-areas and Albemarle-Pamlico models. This outcome is reasonable since farmers with potential soil erosion problems would generally not want to leave the soil in their field vulnerable by destroying crop residues. There may be a link between program participation and access to information. In a stratified sample, 45.8 percent of farmers participating in a program indicated they received some form of advice, whereas only 35.2 percent of farmers not in a program indicated receiving any advice.

The climate variables RAIN and TEMP also had a significant influence on adoption for the combined-areas model. Both were positive, indicating that farmers in warm, humid climates were more likely to destroy crop residues. Limited variation within a single area may not be sufficient to capture subtle climate effects. Temperature and rainfall may be a proxy for the likelihood of pest infestations and outbreaks.

Biological Controls

The use of biological controls is a more recent and modern approach to pest management. Research efforts have focused on identifying and introducing natural enemies as pest control agents. Scientists have also isolated and identified an increasing number of pheromones, which can be used to attract insect pests away from the primary food crop or disrupt breeding. The success of biological controls often depends on the complexity of the pest problem and environmental factors, which may vary from area to area. Although biological controls and pheromones have rather low adoption rates, they are similar practices in that they both use natural means to disrupt the pest cycle. Therefore, these practices are combined for analysis under the general heading of "biological controls."

The sample means for the combined-areas and single-area models are presented in table 4.3. The regions chosen for the single-area adoption models include the Albemarle-Pamlico, Mississippi Embayment, and Southern Georgia areas. These areas were chosen because they had the highest levels of adoption. At least 10 percent of the farmers in each of these areas used biological controls. The model results from the adoption study of biological controls are displayed in table 4.7.

For all areas combined, table 4.3 shows that only about 6 percent of farmers had used any biological control methods. Table 4.7 shows that the predicted probability of adoption for the entire sample was 3 percent calculated at the sample means. The percent correct predictions was 93.9 percent and the pseudo R^2 was 0.34.

The human capital variables did not have strong effects on adoption of biological controls. Farmers who had some college education were significantly more likely to use biological controls in the combined-areas model, but this effect was not evident within the individual areas. In the Southern Georgia model, experience was a positive factor, while having insurance was a negative factor.

The number of acres that a farmer operated had a positive and significant influence on use of biological controls in all models except the Mississippi Embayment model. When natural enemies are absent from the environment, the costs of rearing and releasing a large number of insects for biological control may be prohibitively high, especially for small farm operations. Biological controls may also be more effective over a larger area, where it may be easier to control an infestation if a farm is less likely to have its efforts under-

mined by pest problems from neighboring farms. In these cases, we would expect larger farms to have economies of scale, with lower management and information costs per unit of output. The results support this notion.

A farmer's use of biological controls may also be influenced by crop choice. On low-value per acre crops, biological controls may be too expensive. They may be economical only for high-value crops. Similarly, the most successful biological control programs have been for crops persisting for more than 1 year, such as tree crops. The cropping practices of annual crops are often not suitable for biological controls. Eliminating weeds and disturbing the soil every year may control pests, but may also eliminate natural enemies that overwinter in the soil or crop residue. Farmers who grow cotton (COTTON) or fruit and vegetable crops (FRTVEG) were significantly more likely to adopt biological controls in the combined-areas model. These are both high-value crops, and the fruit and vegetable crops variable includes tree crops. Table 4.5 shows that the predicted probability of adopting biological controls for farmers growing cotton was 22.5 percent, compared with only 2 percent for farmers who did not grow cotton. The use of irrigation had a positive and significant influence on the use of biological controls only in the combined-areas and Southern Georgia models.

Participating in government farm programs had no effect on a farmer's use of biological controls. However, farmers who received some form of pest management information or advice were more likely to adopt biological controls in all models except Southern Georgia. As a pest management strategy, biological

Table 4.7—Change in the percent predicted adoption of biological controls for pest management

Variables	Combined areas	Albemarle-Pamlico	Mississippi Embayment	Southern Georgia
CONSTANT	-0.8572**	-0.2514	-2.3620**	-0.0380
COLLEGE	0.0129**	0.0034	0.0159	0.0206
EXPERIENCE	-0.0060*	-0.0069	-0.0225*	0.0498**
WORKOFF	0.0007	-0.0060	0.0014	0.0058
TENURE	0.0033	0.0205	-0.0146	0.0121
ACRES	0.0056**	0.0282**	0.0112*	0.0403**
COTTON	0.0760**	0.1593**	0.1153**	0.2496**
FRTVEG	0.0476**	—	—	0.0846**
DBL-CROP	-0.0045	-0.0223	-0.0495	-0.0785*
IRRIGATION	0.0107**	0.0118	-0.0048	0.0512**
PROGRAM	-0.0013	-0.0241	-0.0315	0.0071
ADVICE	0.0257**	0.0890**	0.0428**	0.0456*
INSURE	-0.0001	0.0153	-0.0043	-0.0636**
SLP	-0.0094	-0.0087	-0.0002	-0.2980**
PISOIL	-0.0097	-0.0640*	-0.0391	-0.0201
RAIN	0.0188	-0.0431	—	0.1750
TEMP	0.1713**	—	0.5324**	-0.1104
Number of observations	6574	769	822	511
% predicted adoption	3.0	6.7	4.7	7.3
% correct predictions	93.9	90.2	88.4	88.3
Pseudo R^2 [1]	.34	.44	.41	.57

— Variable not included in the adoption model.
** Significant at the 5-percent level.
* Significant at the 10-percent level.
[1] Veall and Zimmerman's pseudo R^2.

Note: For the table, the coefficients estimated from the limited dependent model have been converted into change in percent predicted adoption. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, RAIN AND TEMP), the reported value is the change in the percent predicted adoption given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in the percent predicted adoption with a unit change of 0.01 from the variable mean. See Appendixes 2-A and 2-B for further details.

controls are a relatively new approach, which is rapidly evolving as more and more natural enemies and pheromones are isolated and identified. The number of pests for which biological controls are available is constantly increasing. Therefore, it is expected that farmers who have access to information sources would be more likely to be aware of new types of controls, and more apt to adopt this method as a pest management strategy.

The natural resource variables defining soil quality, SLP and PISOIL, had an insignificant effect on a farmer's use of biological controls in all models with the exception of soil leaching potential, which had a negative impact in the Southern Georgia model. This example illustrates the importance of understanding both the *production-impact* and *environmental-impact* characteristics of the natural resource base on which agricultural production takes place. A producer may be less likely to adopt a chemical-reducing strategy on soil with a high leaching potential, but that land may be the most vulnerable to the transport of chemical residuals.

Higher monthly average rainfall also had no effect on adoption rates. Higher temperature levels, however, were positively associated with higher adoption rates of biological controls in the combined-areas and Mississippi Embayment models. Again, warmer climates may be an indication of a greater potential for pest infestations.

Professional Scouting

Another more recent approach toward pest control involves using a professional scouting service. Professional scouts essentially offer farmers another piece of information or advice about the extent and severity of potential pest infestations. Because professional scouts are trained specialists, they have a special understanding of insect population dynamics and potential impacts on crop yield. Farmers who use scouting often rely on information received from the scout to determine the extent of any pest problem, what pest management strategy to use, and when to use it. With more accurate information, one would expect reduced amounts (if any) of economically wasteful chemical use, but not reduced use of chemicals *per se*. The monitoring of pest populations is usually a component of an integrated pest management system, but does not define IPM.

The sample means for the combined-areas and single-area models are presented in table 4.3. The single area adoption models include the Central Nebraska River Basins, Mississippi Embayment, Southern Georgia Coastal Plain, and Southern High Plains. These areas were chosen because they had the highest levels of adoption. The proportion of farmers who used professional scouting was 14 percent in the Central Nebraska River Basins, 30 percent in the Mississippi Embayment, 18 percent in the Southern Georgia Coastal Plain, and 22 percent in the Southern High Plains (table 4.3). The model results from the adoption study of professional scouting are displayed in table 4.8.

In the combined-areas model, about 15 percent of producers used a professional scout for pest management (table 4.3). The predicted probability of adoption for the entire sample was 0.081 calculated at the sample means (table 4.8). The percent correct predictions was 89.3 percent and the pseudo R^2 was 0.44.

Farmers who had some college education were significantly more likely to use professional scouting in the combined areas, Central Nebraska River Basins, and Mississippi Embayment models. Perhaps farmers with more education recognize the value of monitoring the population and presence of pests in order to apply pesticides only when necessary. In addition, less educated farmers may be less familiar with the services provided by professional scouts. Landownership also had a significant effect on use in these models. The influence in this case, however, was negative, indicating that landowners were less likely to use professional scouts. Crop insurance was positively associated with a farmer's use of professional scouting in the combined areas and Southern High Plains models.

It was expected that it would be easier for producers to personally monitor potential pest problems on smaller farms. The more acres operated, the harder it would be to oversee and regulate populations without the assistance of a professionally trained scout who can take samples and make appropriate pest management recommendations. The model results support this hypothesis for all models. Larger farms are more likely to employ professional scouting services than smaller farms.

Growing cotton was a positive and significant factor associated with professional scouting. A stratified sample shows that 51 percent of cotton growers used professional scouts compared with only 9 percent of farmers who did not grow cotton in the combined areas. Cotton is a high-value crop and is often produced in warm, humid climates prone to pest infestations. It is also a pesticide-intensive crop, with 63.5

percent of the cotton crop acres in the Area Studies Survey data receiving insecticide applications (see table 4.1). Professional scouting may provide cotton farmers a means to reduce pesticide costs by enabling them to schedule pesticide applications only when a pest population reaches a level at which it threatens profitability.

Double-cropping did not significantly affect a farmer's use of professional scouting except in the Southern Georgia Coastal Plain, where the effect was negative. Irrigation, however, was positively and significantly associated with the use of professional scouting in all areas. Irrigation may create living conditions favorable to pests, and these areas may have higher infestation levels. Scouting may be one way to ensure that pest populations remain in check. The predicted adoption of professional scouting by farmers who irrigate is 16.6 percent, compared with only 6.2 percent by farmers who do not irrigate for the combined-areas model (table 4.5).

Farmers in the combined areas and the Central Nebraska River Basins receiving program benefits (PROGRAM) were significantly more likely to use professional scouting as a pest management strategy than those who did not. Receiving some form of pest management information or advice was positively and significantly associated with the use of professional scouting for all areas except the Central Nebraska River Basins. Farmers who seek advice from hired staff, extension service, or chemical dealers may learn about the values and benefits of professional scouting, and therefore adopt this technology as part of a pest management strategy.

The natural resource and climate variables all had an insignificant effect on the adoption of professional scouting for the combined-areas model. The natural

Table 4.8—Change in the percent predicted adoption of professional scouting for pest management

Variables	Combined areas	Central Nebraska	Mississippi Embayment	Southern Georgia	Southern High Plains
CONSTANT	-0.5284	-0.3924**	-5.5675**	3.2183	-1.8629
COLLEGE	0.0337**	0.0488**	0.1434**	0.0036	0.0240
EXPERIENCE	-0.0112*	0.0001	-0.0020	0.0140	-0.0352
WORKOFF	-0.0025	0.0013	-0.0121*	0.0005	0.0058
TENURE	-0.0175**	-0.0424**	-0.1268**	0.0061	-0.0021
ACRES	0.0328**	0.0197**	0.0887**	0.0242**	0.0908**
COTTON	0.1863**	0.0306 [1]	0.5112**	0.2060**	0.0040
DBL-CROP	-0.0274*	—	-0.0680	-0.1068**	0.0685
IRRIGATION	0.0824**	0.1059**	0.1018**	0.1068**	0.1786**
PROGRAM	0.0334**	0.0813**	0.0103	0.0342	-0.0190
ADVICE	0.0580**	0.0221	0.1044**	0.1052**	0.1577**
INSURE	0.0243**	0.0160	0.0171	0.0252	0.1671**
SLP	-0.0011	0.0081	-0.0334	-0.1915	-0.2829**
PISOIL	-0.0299*	-0.0199	-0.0779	0.0472	-0.1813**
RAIN	0.0186	-0.0219	—	-0.1661	—
TEMP	0.0018	—	1.1104**	-0.7981*	0.3026
Number of observations	6574	709	822	511	508
% predicted adoption	8.1	5.9	20.7	7.6	14.5
% correct predictions	89.3	83.1	82.1	89.0	80.1
Pseudo R^2 [2]	.44	.41	.56	.57	.37

— Variable not included in the adoption model.
* Significant at the 5-percent level.
[1] Corn
[2] Veall and Zimmerman's pseudo R^2.

Note: For the table, the coefficients estimated from the limited dependent model have been converted into change in percent predicted adoption. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, RAIN AND TEMP), the reported value is the change in the percent predicted adoption given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in the percent predicted adoption with a unit change of 0.01 from the variable mean. See Appendixes 2-A and 2-B for further details.

resource variables measuring soil characteristics were significant only in the Southern High Plains, and those effects were negative. The Southern High Plains area has the highest average soil leaching potential, and one of the lowest soil productivity averages. The temperature variable was significant only in the Mississippi Embayment model. Although we generally would not expect soil characteristics to affect adoption of professional scouting, it is surprising that climate did not play an important role, particularly in the combined-area model. Pest infestations are more likely to occur in warm, humid climates. In these areas, we would expect professional scouting to be a useful pest management strategy. The results indicate that this is not the case, and that climate has no significant effect on adoption. The climate variables chosen for this study may not be accurate proxies for the potential for pest outbreaks, particularly in the single-area models.

Summary

Although the results from the combined-areas and single-area adoption models vary depending on the region and the pest management practice examined in the estimation, there are some general findings. As expected, human capital had a positive effect on farmers' use of modern pest management technologies, i.e., biological controls and professional scouting. On the other hand, human capital actually had a negative effect on farmers' use of the more traditional pest management strategy of destroying crop residues. Another interesting result was that the number of days worked off the farm was not significant. This implies that the pest management practices analyzed may be neither time-intensive nor time-saving technologies.

Farm size was another significant factor in farmers' use of the modern pest management technologies. Larger farms may have economies of scale that make it easier and more worthwhile for them to adopt newer technologies than smaller farms if the unit cost of using the practice declines with acres. Farm size, however, had no influence on farmers' use of the traditional pest management strategies of crop rotations and crop residue destruction. Cropping practices, especially crop choice and irrigation use, significantly affected farmers' use of all of the pest management practices that were analyzed.

Program participation was positively associated with farmers' use of crop rotations and professional scouting. A significant factor in all of the adoption models was if the farmer had received some form of pest management information or advice. The result was strong and positive in all cases, indicating that the technical assistance and advice farmers receive encourages them to use various pest management strategies.

In general, natural resource characteristics were not important in explaining farmers' use of the modern pest management technologies, but were more important in explaining their use of traditional pest management technologies. Farmers who had less sandy, more highly productive soils were more likely to adopt crop rotations. This result characterizes the types of regions in which crop rotations are most likely to occur. Another resource endowment, the average inherent potential of the soil to erode, characterizes the types of soils where farmers' use of crop residue destruction is most likely to occur. Climate had varying effects on farmers' use of pest management technologies. In many places, higher average monthly rainfall and temperature were associated with the adoption of pest management practices. In general, climate seemed to be more important in predicting use of the traditional pest management practices than the modern practices.

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5. Soil Management

In this chapter, we briefly describe the impacts of soil erosion on water quality and agricultural productivity. We then present the soil management practices that can be used to reduce erosion. The Area Studies survey data are described with respect to the use of specific practices on highly erodible cropland. The results of simple adoption models for practices designed to keep soil on the field and out of nearby water bodies are reported for the combined-areas and single-areas models using the modeling framework presented in chapter 2. The use of Natural Resource Inventory (NRI) points as the sample locations offers a unique opportunity to test the hypothesis that field characteristics are an important determinant of the choice of soil management practices. We then describe the human capital, production, agricultural policy, natural resource, and climate factors affecting adoption.

The choice of soil management practices can have a significant effect on the environment and on farm productivity. In general, producers have an incentive to adopt a new agricultural technology if it is expected to increase economic benefits relative to current practices, through reduced input costs or increased quantity or quality of output. There are long-term and short-term costs to a farmer associated with soil erosion. The sustainability of agricultural production requires that sufficient topsoil depth remain to support crop production. The immediate costs of erosion to the farmer include clogged ditches, uneven terrain, and local air pollution from wind-blown particles. Many of the costs associated with erosion, however, are imposed on offsite resource users. Estimates of offsite damages to water quality from soil erosion range between $5 billion and $17 billion annually (1986 dollars). Most of the erosion costs accrue from impacts on recreation, flooding, water treatments, and municipal and industrial uses (Ribaudo, 1989). Siltation is one of the leading pollution problems in U.S. water bodies (EPA, 1995, 1998). Dust from wind erosion can damage crops and equipment, and have severe impacts on air quality in surrounding areas. Producers will consider on-site costs associated with the use of some agricultural technologies, but producers have little incentive to factor in offsite costs borne by others.

The use of soil conservation practices, such as no-till cultivation or other crop residue management methods, can prevent soil from being transported to waterways while also preserving productivity. Other practices, such as filter strips, specifically prevent soil from entering waterways once the soil has left the field. The second set of practices primarily reduces the off-site impacts of erosion on water quality. These practices generally provide no direct on-farm benefits, so producers may not adopt them unless provided with an incentive to do so. The conservation compliance provisions discussed below provided such an incentive during the survey period.

Summary of Soil Management Practices and Data from the Area Studies Survey

The Area Studies survey sample contains a wide distribution of soil erosion rates and adoption rates of soil management practices. Figure 2.3 displays the percent of highly erodible cropland acres by region.[1] The areas in the survey that had more than 30 percent of their cropland acres in the highly erodible category are the Susquehanna, Mid-Columbia, Central Nebraska and Snake River Basins, and the Southern High Plains. Cropland in the Snake River Basin and the Southern High Plains was susceptible primarily to wind erosion rather than the sheet and rill erosion that dominates in the other areas. Areas with the least amount of cropland in the highly erodible category were the Southern Georgia Coastal Plain and the Mississippi Embayment. These areas are characterized as floodplains and generally are flat.

Farmers can choose from a variety of soil conservation practices to control erosion, but the profitability and ease of use of these practices will depend on human capital, cropping practices, natural resources, and policy constraints. Farmers must also perceive that soil erosion is a significant problem before they take actions to reduce soil loss (Norris and Batie, 1987). The Area Studies survey instrument included a list of frequently used soil conservation practices, from which the farmer selected the practices used that year. Some of the soil management practices were designed to hold soil on the field, and some were designed to prevent soil from being transported beyond the site.

To identify the factors that affected adoption of soil conservation technologies, we separated the models of soil conservation adoption into three groups: (1) the

[1] See chapter 2 for a definition of highly erodible land.

choice of any soil conservation practice; (2) the choice of soil conservation practices that specifically prevent soil from entering nearby waterways, thus reducing potential off-site damages; and (3) the choice of selected tillage practices that are associated primarily with on-site benefits. Each of these groups is described more fully below. The factors that influence a farmer's use of a particular soil management practice may differ from those that appear to be significant when several practices are analyzed as a group. In particular, the determinants of the farmer's decision to adopt a technology with on-site benefits may differ from those that affect the farmer's choice of a practice with only off-site benefits. To encourage farmers to use preferred technologies, one needs an understanding of which factors are most important in farmers' decision-making processes.

The core variables that we used to assess a farmer's adoption of a certain production practice are described in chapter 2. The following discussion presents additional variables that we included in the models of farmers' use of soil management practices.

Conservation policies can influence the use of soil management practices by increasing the costs to producers who do not control soil erosion on highly erodible lands. The 1985 Farm Bill linked farm program benefits with soil conservation efforts. Under the 1985 Farm Bill, agricultural producers were subject to conservation compliance if they received farm program benefits and cultivated highly erodible cropland. Land is considered highly erodible if potential soil loss due to sheet and rill, or wind, erosion divided by a soil loss tolerance factor,[2] is greater than or equal to 8. Farmers subject to conservation compliance were required to have an approved conservation plan in place by January 1990 and had to fully implement the plan by January 1995. The conservation plan often included the use of particular soil management technologies or cropping practices. Farm program benefits could be denied if a farmer was not in compliance.

Magleby et al. (1995) estimated that after the conservation compliance provisions were implemented, about 105.5 million cropland acres were considered highly erodible, a decrease of 11.8 percent from the 1987 level of 117.3 million cropland acres. Highly erodible cropland is roughly one-third of total U.S. cropland acres. They also estimated the benefits from reduced soil erosion as a result of conservation compliance as follows: $325 million in productivity benefits, $21.7 billion in water quality benefits, and $3 billion in dust reduction benefits.

Producers who participated in the Area Studies survey were asked if they received farm program benefits (e.g., price supports, crop quotas, or the Conservation Reserve Program (CRP)). About 18 percent of the farmers who were sampled were deemed subject to conservation compliance (COMPLY) if they received farm program benefits and cultivated highly erodible cropland, as defined by the NRCS. For the soil management adoption models, the compliance variable is used instead of the PROGRAM variable described in chapter 2. Farmers may also receive technical assistance from the NRCS to develop a conservation plan (CVPLAN). About 53 percent of farmers had implemented a conservation plan. This number is higher than the number of farmers subject to compliance since farmers can voluntarily receive technical assistance from the NRCS to develop a conservation plan regardless of whether they had highly erodible land or received farm program benefits. CVPLAN is the variable used in the soil management model instead of the ADVICE variable described in chapter 2.

A farmer's selection of soil conservation technology may also be influenced by the crop(s) raised. Certain crops contribute less to soil erosion than others. For example, small grains and hay are closely sown crops, and therefore, expose less soil to the elements than row crops. Agricultural producers who cultivate small grains probably would have less need for adopting soil conservation practices, since they already may have a low rate of soil erosion. Nonetheless, there could be a positive association between such crops and conservation practices, since farmers may be growing small grains as part of an overall soil conservation plan. Grains and hay crops (defined as wheat, barley, oats, rye, alfalfa, or other hay) were produced by about 22 percent of farmers. Row crops, on the other hand, are considered to contribute more to soil erosion than grains. Row crops (defined as corn, soybeans, cotton, tobacco, potatoes, or sorghum) were grown by about 78 percent of farmers. Two crop dummy variables (ROWCROP, GRAIN) were used to capture the effects of cropping patterns on the adoption of soil management practices. The use of animal wastes (MANURE) was also included in the analysis. The incorporation of organic matter to the soil adds structure as well as nutrients and may slow erosion rates.

[2] The soil loss tolerance factor is set by NRCS and is based on the erosion rate above which soil productivity will be reduced.

Natural resource characteristics associated with the farm unit may be an important determinant of adoption. Since some soil management practices are targeted for either sheet and rill or wind erosion, specific variables (RKLS and WIND) were used in some cases rather than the general measure, EROTON. These variables are constructed from the NRI-derived data associated with each field observation. In addition, a variable (WATERBODY) was included that indicates whether the field is next to a water body.[3]

As mentioned above, three groupings of soil management practices are analyzed using the framework described in chapter 2. We report the results of the analyses on (1) the adoption of any conservation practice, (2) the adoption of soil conservation practices to protect water quality, and (3) the adoption of conservation tillage. Figure 5.1 shows the adoption of these soil management practices by crop. For each soil management category, the first adoption model includes all 10 of the Area Studies regions combined (referred to as the "combined-areas" model) and the other models analyze individual regions (referred to as the "single-area" models). An analysis of the individual Area Studies regions was conducted to show the location-specific nature of adoption, and how the factors affecting adoption may differ between regions. The selection criteria for choosing the regions for the "single-area" models were based on whether there were a sufficient number of observations in an adoption category and on the severity of the soil erosion problem in the area. That is, results from the adoption models of single areas were not reported if those areas had few producers who adopted a soil conservation technology and had low soil erosion rates on average.

Adoption of Soil Management Practices

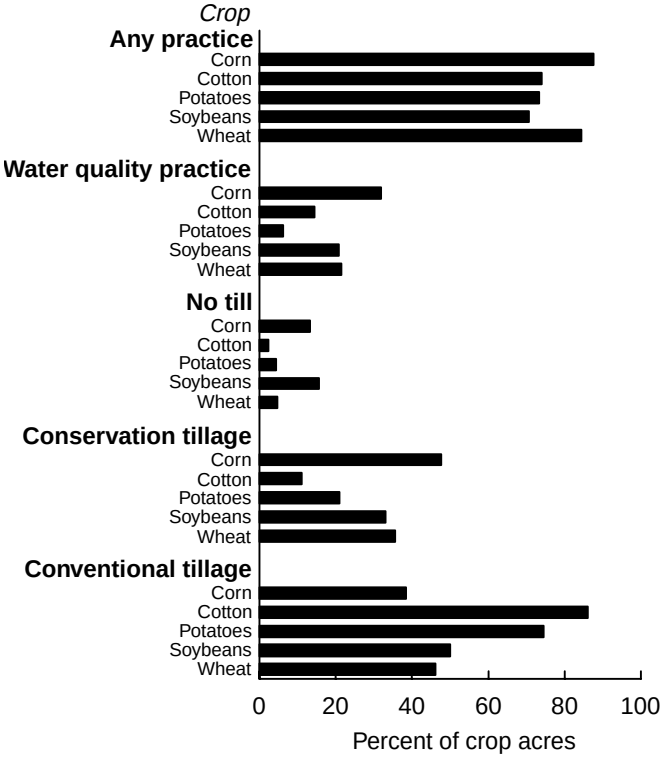
Adoption of Any *Soil Conservation Practice*

The first adoption model focuses on the factors that affect the use of *any* soil conservation practice on cropland, specifically conservation tillage, crop residue use, chiseling and subsoiling, contour farming, conservation cover or green manure crops, grass and legumes in rotation, strip cropping, terracing, grassed waterways, filter strips, grade stabilization structures, and critical area planting. The "Glossary" (box on p. 64) provides definitions of the soil conservation practices covered in the Area Studies survey. This category includes practices that specifically prevent soil from entering waterways once it has left the field as well as those that maintain soil on the field. Conservation practices that keep soil on the field contribute directly to on-farm productivity as well as to off-farm water quality. The large number of practices (12) included in the "any" category may mask the effects of individual factors, therefore we tested whether the factors that affected the adoption of *any* conservation practice differed from those that influenced the choice of a particular practice or group of practices.

Figure 5.2 shows the adoption of *any* soil conservation practice by region, and figure 5.3 presents adoption on highly erodible land. For each area, over half of the highly erodible cropland acres were under some kind of soil conservation practice. The area that cultivated almost all of its highly erodible cropland using *any* soil conservation practice was the Illinois/Iowa Basin.

The sample means for the combined-areas and single-area models are presented in table 5.1. The model results, along with the significance level, from the adoption study of *any* soil conservation practice are displayed in table 5.2.

Figure 5.1
Adoption of soil management practices by crop



[3] Respondents were asked if the field was beside a stream, river, lake, pond, canal, or ditch.

Figure 5.2

Adoption of any soil conservation practice by region

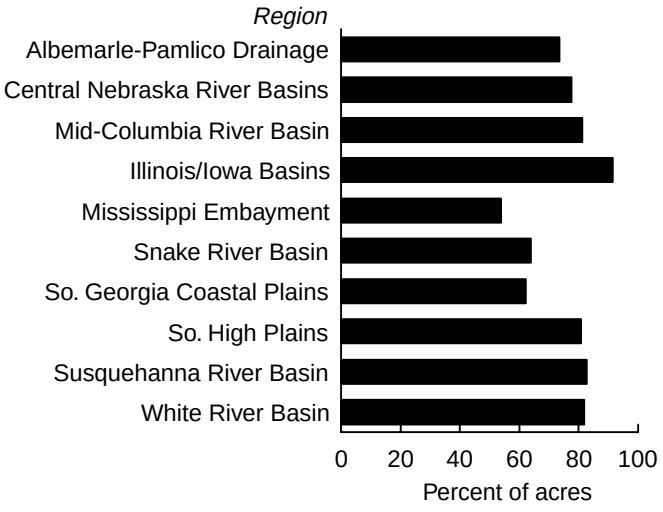


Figure 5.3

Adoption of any soil conservation practice on highly erodible cropland by region

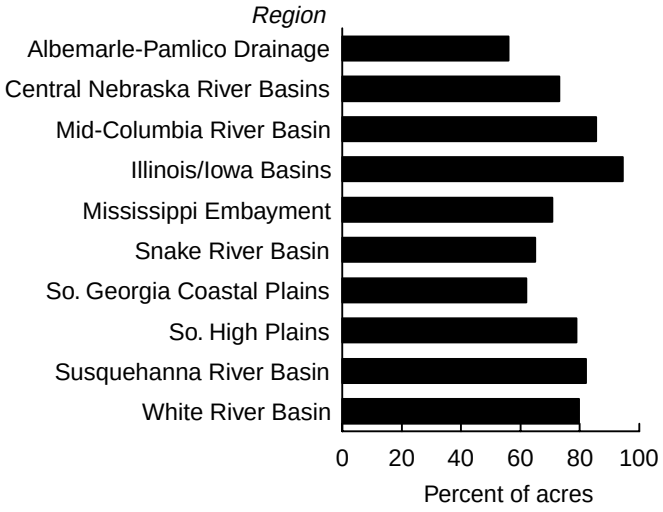


Table 5.1—Sample means from soil conservation adoption models

Variables	Combined areas	Albemarle-Pamlico	Central Nebraska	Mid-Columbia River Basin	Illinois/Iowa River Basins	Snake River Basin	Southern High Plains	Susquehanna River Basin	White River Basin
ANY PRACTICE	.75	.72	.78	.83	.92	.65	.83	.83	.83
WATER QUALITY PRACTICE	.22	.21	.26	.25	.40	.04	.10	.32	.30
COLLEGE	.44	.34	.38	.71	.38	.60	.54	.14	.43
EXPERIENCE	24	25	24	22	25	21	23	22	25
WORKOFF	32	35	30	14	41	35	24	48	64
TENURE	.38	.34	.44	.43	.37	.62	.36	.61	.41
ACRES	1688	1333	1625	3111	910	2550	1972	445	932
ROTATION	.53	.74	.42	.56	.82	.66	.19	.68	.79
ROWCROP	.78	.78	.77	.04	.95	.13[1]	.75	.59	.91
GRAIN	.22	.29	.25	.67[2]	.08	.32[2]	.27	.51	.11
DBL-CROP	.05	.16	.00	.18	.01	.00	.06	.04	.02
MANURE	.09	.05	.10	.02	.19	.09	.05	.63	.10
IRRIGATION	.27	.08	.41	.24	.02	.81	.45	.02	.00
COMPLY	.18	.12	.24	.34	.13	.20	.56	.12	.11
CVPLAN	.54	.48	.50	.76	.56	.78	.78	.51	.43
INSURE	.40	.27	.42	.57	.63	.27	.70	.04	.17
WATERBODY	.42	.58	.27	.23	.35	.34	.07	.17	.39
SLP	119	124	126	143	91	150	151	100	111
PISOIL	.80	.53	.84	.88	.94	.82	.69	.68	.91
EROTON	33	21	47	58	27	37	70	58	28
RKLS	22	21	27	41	25	8	5	58	28
WIND	12	0	19	17	1	29	66	0	.18
RAIN	3.0	4.0	2.1	1.1	3.0	1.2	1.6	3.4	3.4
TEMP	55	60	49	49	50	44	58	51	52
Number of observations	6398	720	703	242	1266	537	508	380	737

Refer to Chapter 2 for variable definitions and units. “Any Practice” includes conservation tillage, crop residue use, chiseling and subsoiling, contour farming, conservation cover or green manure crops, grass and legumes in rotation, strip cropping, terracing, grassed waterways, filter strips, grade stabilization structures, and critical area planting. “Water Quality Practice” includes grassed waterways, filter strips, grade stabilization structures, and critical area planting.

[1] Potatoes.

[2] Wheat.

In the combined-areas model, about 75 percent of producers used at least one kind of soil conservation practice. Table 5.3 shows that the predicted adoption of these practices for all areas combined was 83.4 percent calculated at the sample means. The percent of correct predictions was 83 percent and the pseudo R^2 was 0.46. The regions chosen for the single-area adoption models were the Albemarle-Pamlico, Central Nebraska, Mid-Columbia River, Illinois/Iowa, Snake River, Susquehanna, and White River Basins, and the Southern High Plains. Row 1 of table 5.1 shows that a large proportion of agricultural producers in each region used soil conservation practices. The lowest proportion of adopters in this model came from the Snake River Basin, with 65 percent of farmers using at least one type of soil conservation practice. The percent of farmers using conservation practices in the Southern Georgia Coastal Plain and the Mississippi Embayment were 64 and 54 percent, respectively. These areas, however, did not have severe soil erosion problems on average and, therefore, were not included in the empirical analysis.

The coefficients for COLLEGE, EXPERIENCE, and WORKOFF were not statistically significant at the 5-percent level in the combined-areas model, but, in the Susquehanna River Basin, more experienced farmers and those who worked more days off-farm were more likely to adopt *any* conservation practice. The effect of farm ownership (TENURE) on the adoption of *any* soil conservation practice was negative and statistically

Table 5.2—Change in percent predicted adoption of any soil conservation practice

Variables	Combined areas	Albemarle-Pamlico	Central Nebraska	Mid-Columbia River Basin	Illinois/Iowa River Basins	Snake River Basin	Southern High Plains	Susquehanna River Basin	White River Basin
CONSTANT	-1.7266**	-2.7967**	0.1719	-0.3041	-0.1989	0.0491	-4.4499*	-2.0234**	-0.7195**
COLLEGE	0.0186*	0.0360	0.0247	-0.0023	0.0251*	-0.0107	0.0024	-0.0033	0.0178
EXPERIENCE	0.0063	-0.0064	0.0193	0.0357*	0.0127	-0.0357	-0.0154	0.0482**	-0.0124
WORKOFF	-0.0016	0.0074	-0.0043	0.0040	0.0030	-0.0012	-0.0036	0.0159**	-0.0006
TENURE	-0.0230**	-0.0518	-0.0460*	-0.0340	-0.0324**	0.1046**	0.0213	-0.0320	-0.0083
ACRES	0.0100**	0.0456**	-0.0350**	0.0023	0.0191**	-0.0366	0.0056	0.0543**	0.0345**
ROTATION	0.0961**	0.1093**	0.1358**	0.0846**	0.0160	0.1709**	0.0133	0.0660**	0.1172**
ROWCROP	0.0603**	0.0835*	—	—	—	0.2444**[1]	—	—	—
GRAIN	-0.0735**	—	-0.2587**	0.1427**[2]	-0.0403**	0.2556**[2]	0.0609*	-0.0916**	-0.1495**
DBL-CROP	0.0443*	-0.0319	—	-0.0390	—	—	—	—	—
MANURE	0.0262	0.1030	0.0792	—	0.0012	-0.0756	0.0233	0.1004**	0.0310
IRRIGATION	0.0132	0.1603	0.0071	0.1279**	—	-0.1155	-0.0126	—	—
COMPLY	0.0222	-0.0667	0.0270	0.1413**	0.0597**	0.1015	-0.0434	0.0019	0.0244
CVPLAN	0.02904**	0.2889**	0.1581**	0.0910**	0.0537**	0.3826**	0.2966**	0.0260	0.1221**
INSURE	0.0253**	0.0434	-0.0172	-0.0132	0.0129	0.1285**	0.0030	—	-0.0022
WATERBODY	0.0043	0.0114	-0.0409	-0.0472	0.0146	-0.1315**	0.0249	0.1303**	0.0252
SLP	0.0091	0.2492**	0.0218	-0.0504	-0.0172	-0.1292	0.0259	-0.0836	-0.0439
PISOIL	0.1174**	0.1272	0.0637	0.1551*	-0.0749	0.1602	0.1680*	0.1595**	-0.1035
EROTON	-0.0037	-0.0059	0.0187	-0.0240	0.0001	-0.0330	0.0213	0.0471**	-0.0038
RAIN	0.1518**	1.4813**	-0.1969	0.1039	0.2053**	-0.0822	—	1.2598**	0.6130**
TEMP	0.3400**	—	—	—	—	—	1.0330*	—	—
Number of observations	6398	720	703	242	1266	537	508	380	737
% predicted adoption	83.4	77.1	89.2	93.9	93.9	68.1	90.8	91.3	86.9
% correct predictions	83	78	89	88	92	75	88	86	84
Pseudo R^2 [3]	.46	.34	.63	.51	.15	.39	.51	.41	.24

— Variable not included in the adoption model.
** Significant at the 5-percent level.
* Significant at the 10-percent level.
[1] Potatoes only.
[2] Wheat only.
[3] Veall and Zimmerman's pseudo R^2.
Note: "Any Practice" includes conservation tillage, crop residue use, chiseling and subsoiling, contour farming, conservation cover or green manure crops, grass and legumes in rotation, strip cropping, terracing, grassed waterways, filter strips, grade stabilization structures, and critical area planting. For the table, the coefficients estimated from the limited dependent model have been converted into change in percent predicted adoption. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, RKLS, WIND, RAIN AND TEMP), the reported value is the change in the percent predicted adoption given a one-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in the percent predicted adoption with a unit change of 0.01 from the variable mean. See Appendixes 2-A and 2-B for further details.

significant, -0.023 in the combined-areas model. Farm ownership reduced predicted adoption to 82 percent, whereas predicted adoption is 84.3 percent for producers who did not own their farm (table 5.3). From a policy perspective, however, this relatively small difference in adoption may not be important. In the Illinois/Iowa Basins, land tenure was negatively and significantly correlated with the adoption of *any* soil conservation practice, but was positively correlated with adoption in the Snake River Basin. The result obtained here indicates that, contrary to commonly held notions, renters may have the same, if not more, incentives to make investments to preserve soil on the field as landowners. Some reasons for this could be that renters lease land for long periods or they could be related to landowners, and therefore, may have an incentive to maintain soil productivity for subsequent growing seasons. In addition, renters may be held accountable for property damages or may have rental contracts that require the use of conservation practices. The data do not allow for testing these hypotheses. In the combined-areas and Snake River Basin models, farmers who had crop insurance (INSURE) were more likely to adopt any soil conservation practice.

Many studies on the factors that motivate soil conservation investments have found that larger farms are more likely to invest in soil conservation practices (Young and Shortle, 1984; Napier et al., 1984; and Norris and Batie, 1987). Larger farms are often associated with lower management and information costs per unit of output. The result from this model supported this hypothesis. Farm size (ACRES) had a positive influence on the adoption of *any* soil conservation practice in most areas. Agricultural producers in the combined sample who cultivated 500 acres of land were less likely to adopt any soil conservation practice, about 82.8 percent, compared with 85 percent for farmers who operated 5,000 acres (table 5.3). However, the number of acres operated had no impact on the adoption rates in the Mid-Columbia River, Snake River, and the Southern High Plains areas, and had a negative effect on adoption in the Central Nebraska Basins. These four areas had larger farms than other areas in the study. This result indicates that there may be some positive effect on adoption from farm size in regions with relatively small farm sizes, but the effect is less pronounced as average farm size increases.

Crop rotations can be used as a strategy for both nutrient and pest management, since planting the same crop over many years can contribute to depleted soil nutrients as well as increased pest problems, such as weediness and insect infestation. The use of soil conservation systems that leave the soil relatively undisturbed, e.g., crop residue management and conservation tillage, can increase weed levels and the need for more herbicides. However, these soil conservation technologies also help to replenish soil nutrients and increase water-holding capacity of the soil (Gill, 1997). The effect of crop rotations (ROTATION) on the adoption of *any* soil conservation practice were positive for six of the eight areas and the combined sample. The rotation variable was not significant for the Illinois/Iowa Basins and the Southern High Plain regions.

The type of crop grown had a significant effect on the adoption of *any* soil conservation practice.[4] In almost all cases, the probability that a farmer is adopting *any* soil conservation practice significantly increased with row crops, which are generally erosive, and decreased with grains. This result suggests that farmers may view crop choice as a substitute for conservation practices. Only in the Mid-Columbia and Snake River Basins, where wheat is the major crop grown in the area, was the adoption of any soil conservation practice more likely if a grain was grown.

Double-cropping (DBL-CROP), or growing more than one crop per year on a field, is a measure of cropping intensity. Double-cropping had no impact on the adoption of *any* soil conservation practice. Whether or not a farmer applied manure (MANURE) to a field did not affect the adoption of *any* soil conservation practice, except in the Susquehanna region, where manure applications increased the probability of adopting *any* soil conservation practice. In the Susquehanna River Basin, dairy farms predominate, and close to 63 percent of the sample in the soil conservation adoption model indicated that they applied manure on the field.

The use of irrigation (IRRIGATION) also did not influence farmer decisions to use *any* soil conservation system. In general, irrigation may contribute to the movement of soil in areas subject to sheet and rill erosion, but in areas subject to wind erosion, irrigation may help keep soil on the field. In fact, the results show that the effect of irrigation use on the adoption of

[4] Since some agricultural producers cultivated both grain and row crops in their fields, each crop dummy variable can be considered apart from the other in the combined regional adoption models. For the single areas, the crop dummy variable chosen to be incorporated into the model depended on either model fit, predominant crop in a region, or number of observations.

soil conservation practices may be either positive or negative, depending on the area.

Conservation compliance (COMPLY) was not a significant factor in motivating farmers to adopt *any* soil conservation practice, except in the Mid-Columbia River and Illinois/Iowa Basins where the effect of conservation compliance was positive. However, technical assistance (CVPLAN) had a positive and significant effect on the use of any soil conservation system in all regions, except the Susquehanna River Basin. This is an interesting result since most of the producers who developed a conservation plan voluntarily obtained technical assistance from the Extension Service or Soil Conservation District. Only a subset of these producers were subject to conservation compliance (table 5.1). This indicates that technical assistance is used by farmers who voluntarily seek soil management technologies to control erosion. Table 5.3 highlights this difference. There is only a 2.2-percentage-point difference in farmers' use of any conservation practice between farmers who are subject to conservation compliance versus those who are not. On the other hand, 93.1 percent of farmers with a conservation plan used a conservation practice compared with 62.1 percent of farmers who did not have a conservation plan.

The effectiveness of soil conservation technologies on a field depends on the natural resource endowments of that site. However, farmers may gain no direct benefits from preventing off-site damages. Field location next to a water body had no effect on the use of any conservation practice except in the Susquehanna Basin. Soil leaching potential (SLP) is an index that measures the potential of chemicals to leach through soil into ground water. As expected, SLP did not have a significant impact on the adoption of soil conservation practices overall.

A soil productivity index (PISOIL) was calculated to measure soil quality for root growth (see Chapter 2). The index values range from 0 to 1, with higher values indicating more productive soils. Highly productive soils were hypothesized to encourage farmers to adopt soil conservation practices that maintain soil on the field. Since high levels of soil erosion will reduce a field's productive topsoil, agricultural producers may have an incentive to prevent potential decreases in crop yields resulting from erosion. In other words, the private costs of erosion are higher for productive soils. For the combined-areas and Susquehanna models, the greater the productive capacity of soil the more likely that producers employed soil conservation practices.

The inherent potential of soil to erode (EROTON) due to rainfall and wind is measured in tons per acre per year. A farmer's perception of an erosion problem is an important determinant of soil management decisions (Norris and Batie, 1987; and Ervin and Ervin, 1982). Inherent erosion levels had no significant

Table 5.3—Percent predicted adoption: Combined areas

Variables	Any conservation practice	Conservation practices to protect water quality	No-till	Mulch-till/ ridge-till	Conventional tillage
Land tenure	**			**	**
Yes	82.0	16.7	8.9	28.3	62.8
No	84.3	16.8	9.8	31.3	58.9
Land operated	**		**	**	**
500 acres	82.8	17.0	8.4	28.2	63.3
5,000 acres	85.0	16.3	12.2	35.0	52.8
Conservation compliance		**	**		**
Yes	85.2	25.7	14.3	30.2	55.5
No	83.0	15.2	8.6	30.1	61.3
Conservation plan	**	**	**		**
Yes	93.1	24.0	11.2	30.7	58.1
No	62.1	10.7	7.6	29.5	62.9
Percent adoption at means	83.4	16.8	9.4	30.2	60.3

** Significant at the 5-percent level.
* Significant at the 10-percent level.
Note: "Any Practice" includes conservation tillage, crop residue use, chiseling and subsoiling, contour farming, conservation cover or green manure crops, grass and legumes in rotation, strip cropping, terracing, grassed waterways, filter strips, grade stabilization structures, and critical area planting. "Water Quality Practice" includes grassed waterways, filter strips, grade stabilization structures, and critical area planting.

Glossary of Soil Conservation Practices

Chiseling and subsoiling loosens the soil, without inverting and with a minimum of mixing of the surface soil, to shatter restrictive layers below normal plow depth to improve water and root penetration and aeration.

Conservation cover is the establishment and maintenance of permanent vegetative cover to protect soil and water resources.

Conservation tillage refers to any tillage and planting system that leaves at least 30 percent of the soil surface covered by plant residue after planting to reduce soil erosion by water; or, where wind erosion is the primary concern, at least 1,000 pounds per acre of flat small grain residue-equivalent are on the surface during the critical erosion period. Some examples of conservation tillage include mulch-, ridge-, and no-till. For the Area Studies survey, the following definitions apply (Bull and Sandretto, 1996).

No-till - A tillage system that leaves the soil undisturbed from harvest to planting except for nutrient injection. Planting or drilling is accomplished in a narrow seedbed or slot.

Ridge-till - A tillage system that leaves the soil undisturbed from harvest to planting except for nutrient injection. Planting is completed in a seedbed prepared on ridges that retain residue on the surface between ridges.

Mulch-till - Any other tillage system, besides ridge or no-till systems, that disturbs the soil before planting, but leaves 30 percent or more plant residue after planting.

Contour farming refers to farming sloping land in such a way that preparing land, planting, and cultivating are done on the contour. This includes following established grades of terraces or diversions.

Cover or green manure crops are crops of close-growing grasses, legumes, or small grains grown primarily for seasonal protection or soil improvement. Use of these crops adds organic matter, such as nitrogen when plowed into the field, and improves infiltration, aeration, and tilth.

Critical area planting refers to planting vegetation on highly erodible or critically eroding areas.

Crop residue use refers to using remains of crop plants after harvest to protect cultivated fields during critical erosion periods and supply organic matter to the soil.

Filter strips are strips or vegetative areas for removing sediment, organic matter, and other pollutants from runoff and waste water. Filter strips are typically applied at the lower edge of fields, on fields, on pastures, or in manure-spreading areas adjacent to water bodies.

Grade stabilization structures are used to control the grade and head cutting in natural or artificial channels.

Grass and legumes in rotation refers to planting grasses and legumes or a mixture of them and maintaining the stand for a definite number of years as part of a conservation cropping system.

Grassed waterways are natural or constructed channels that are shaped or graded to required dimensions and established with suitable vegetation for the stable conveyance of runoff.

Strip cropping refers to growing crops in a systematic arrangement of strips or bands, on the contour or across the general slope, to reduce water erosion. The crops are arranged so that a strip of grass or close-growing crop is alternated with a strip of clean-tilled crop or fallow or a strip of grass is alternated with a close-growing crop. To control wind erosion, wind-resisting crops are grown in strips alternating with row crops or fallow and arranged at angles to offset adverse wind effects.

Terracing refers to an earth embankment, a channel, or a combination ridge and channel constructed across the slope.

Source: National Water Data Exchange, U.S. Department of the Interior, Geological Survey.

impact on the adoption of *any* soil conservation practice except in the Susquehanna model. This unexpected result seems to indicate that producers base adoption decisions on other factors, such as labor cost savings associated with reduced tillage or conservation compliance policies, rather than sustaining on-site productivity by reducing soil erosion levels. Farmers' concern about erosion may have been lessened due to technologies that enhance yields, such as pesticides and chemical fertilizers (Young and Shortle, 1978). And, as previously discussed, farmers may also use their choice of crops to manage erosion instead of adopting the conservation practices included in this study. In addition, the higher adoption of practices on HEL captured by the conservation compliance variable indicates that farmers have an increased incentive to control erosion when the costs of erosion (noncompliance) are high.

Climate can play a major role in the use of soil conservation practices. High monthly average rainfall (RAIN) could increase the potential for soils to erode, and high monthly temperatures (TEMP) in arid regions can dry out soil, thereby leaving soil more vulnerable to wind erosion. Rainfall had a positive influence on the adoption of *any* soil conservation practice in all models except those for the Central Nebraska, Mid-Columbia River and Snake River Basins.[5] However, these three areas had lower than average rainfall per month than for all areas combined. High temperatures in the combined areas and the Southern High Plains increased the probability of farmers' adopting soil conservation practices.

Soil Conservation Practices to Protect Water Quality

While all the soil conservation practices included in the preceding models prevent soil from entering waterways, a subset of practices is designed specifically to prevent soil from being transported to waterways once the soil has left the field. The second adoption model tries to capture the extra soil conservation efforts that producers undertake to prevent soil from entering waterways. A substantial share of the social benefits from the adoption of these practices likely accrue off the farm, such as to downstream water quality. Factors influencing the adoption of practices designed primarily to enhance environmental quality were expected to differ from those that increased producer profits (Pample and van Es, 1977). Soil conservation practices included in this category were grassed waterways, filter strips, grade stabilization structures, and critical area planting. Ninety-three percent of farmers who had adopted these practices also used at least one soil conservation practice that would maintain soil productivity (an on-farm benefit). The water quality-enhancing practices are typically located at the edge of a field or on steep slopes, and these practices are effective in controlling only sheet and rill erosion.

[5] The temperature and rainfall variables in the single-area adoption models were highly correlated. Since rainfall is the major contributor to soil erosion, a choice was made to retain the rainfall variable in the model and exclude temperature. One exception was made for the Southern High Plains region, where erosion due to wind was the major contributor to soil erosion.

Figure 5.4
Adoption of water quality practices by region

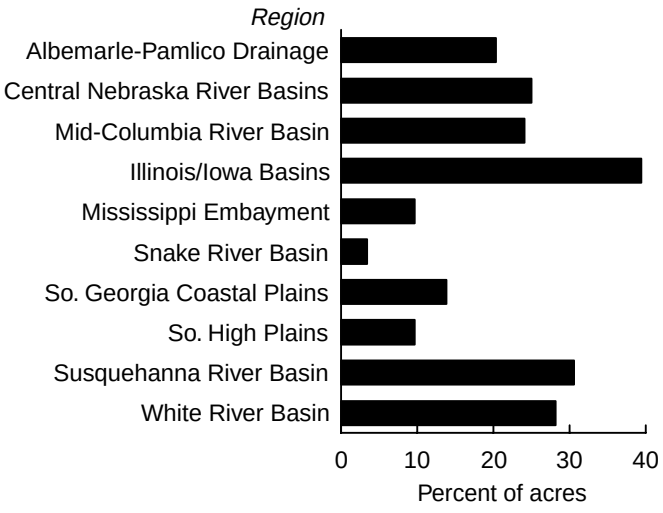


Figure 5.5
Adoption of water quality practices on highly erodible cropland by region

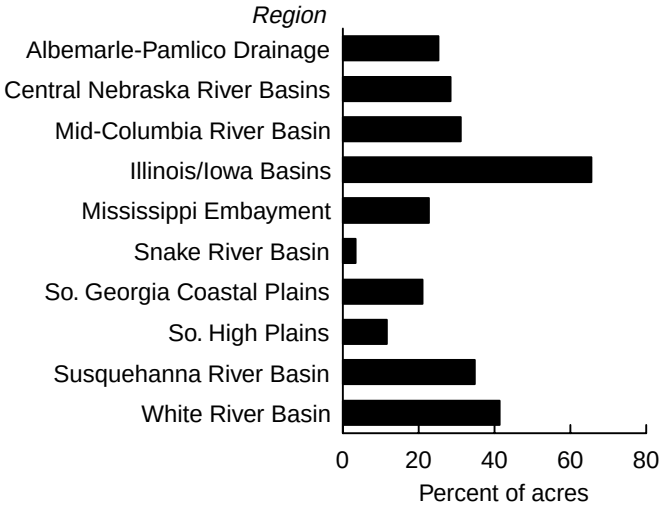


Figure 5.4 shows the use of soil conservation practices that protect water quality by region, and figure 5.5 shows their use on highly erodible cropland. As expected, there was very little adoption of these practices on highly erodible land in the Southern High Plains and the Snake River Basin where wind is the chief cause of soil erosion. The greatest level of highly erodible land cultivated in combination with water quality practices was in the Illinois/Iowa River Basins, 66 percent, and the White River Basin, 41 percent.

The sample means for the variables in the combined-areas and single-area models are presented in row 2 of table 5.1. The model results, along with the significance level, from the adoption study of soil conservation practices to protect water quality are displayed in table 5.4.

Twenty-two percent of farmers in the combined sample had adopted at least one of the soil conservation practices that primarily protect water quality. A stratified sample statistic indicated that these farmers had higher than average potential sheet and rill erosion rates. For the sample, the average potential soil erosion rate was 22 tons per acre per year due to rainfall, whereas the rainfall erosion rate for the farmers who had adopted water quality practices was about 34 tons per acre per year. Column 1 of table 5.4 shows that the predicted

Table 5.4—Change in percent predicted adoption of soil conservation practices to protect water quality

Variables	Combined areas	Albemarle-Pamlico	Central Nebraska	Mid-Columbia River Basin	Illinois/Iowa River Basins	Susquehanna River Basin	White River Basin
CONSTANT	0.1741	-1.2794**	-0.5332**	0.5186	0.9848**	-0.7997	-1.3991**
COLLEGE	0.0118	0.0429	0.0362	0.0613	0.0004	0.1631**	-0.0136
EXPERIENCE	-0.0036	-0.0195	0.0076	-0.0710**	-0.0261	0.0168	-0.0061
WORKOFF	0.0016	0.0004	-0.0012	0.0067	0.0094	0.0064	0.0091
TENURE	-0.0006	0.0116	-0.0475	-0.0522	0.0044	-0.0209	-0.0295
ACRES	-0.0028	0.0250*	-0.0170	0.0090	-0.0342	0.0222	0.0489**
ROTATION	0.0671**	0.0587	0.0575*	0.1645**	0.0954**	0.1006*	0.1451**
ROWCROP	0.0426**	0.0195	0.0768	—	—	—	—
GRAIN	0.0191	—	-0.0528	0.2389**[1]	0.0315	-0.0014	0.0813
DBL-CROP	-0.0140	-0.0703*	—	-0.0740	—	—	—
MANURE	0.0424**	-0.0579	0.0768*	—	0.0451	0.0449	0.0873
IRRIGATION	-0.0143	0.1830**	-0.0250	-0.2505**	—	—	—
COMPLY	0.0921**	0.0032	0.0789**	0.1327**	0.1863**	0.1639**	0.1790**
CVPLAN	0.1349**	0.1976**	0.1242**	0.1251	0.1567**	0.0822	0.1364**
INSURE	0.0122	0.0507*	0.0308	-0.0786	0.0048	—	0.0757*
WATERBODY	0.0492**	0.0904**	0.0182	0.0585	0.1095**	0.0610	0.0255
SLP	0.0043	0.2159**	0.0122	-0.3184	0.0059	0.1058	0.0750
PISOIL	0.0640*	0.2326**	-0.1519	-0.5592**	0.3235*	-0.2552**	0.0267
RKLS	0.0083**	0.0180	—	—	0.0338**	0.0605**	-0.0020
WIND	-0.0143**	—	-0.1543**	0.0173	-0.0381**	—	-0.0083*
RAIN	0.1009*	0.2771	0.6583**	-0.0620	-1.2643**	0.2862	0.6989**
TEMP	-0.1726	—	—	—	—	—	—
Number of observations	6398	720	703	242	1266	380	737
% predicted adoption	16.8	15.7	16.4	17.4	38.8	29.7	27.9
% correct predictions	79	83	79	79	66	73	71
Pseudo R^2 [2]	.30	.32	.39	.39	.18	.20	.17

— Variable not included in the adoption model.
** Significant at the 5-percent level.
* Significant at the 10-percent level.
[1] Wheat only.
[2] Veall and Zimmerman's pseudo R^2.

Note: "Practices to Protect Water Quality" include grassed waterways, filter strips, grade stabilization structures, and critical area planting. For the table, the coefficients estimated from the limited dependent model have been converted into change in percent predicted adoption. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, RKLS, WIND, RAIN AND TEMP), the reported value is the change in the percent predicted adoption given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in the percent predicted adoption with a unit change of 0.01 from the variable mean. See Appendixes 2-A and 2-B for further details.

probability of the combined-areas model at the sample means was 16.8 percent. The percent correct predictions was 79 percent and the pseudo R^2 was 0.30. The single-area adoption models included Albemarle-Pamlico, Central Nebraska, and the Mid-Columbia, Illinois/Iowa, Susquehanna, and White River Basins. The Southern High Plains and the Snake River Basin which were included in the models assessing the adoption of *any* soil conservation, were omitted from this analysis because in these areas wind is the prevalent soil erosion factor, and, therefore, there is very little adoption of practices to protect water quality. The proportion of farmers who adopted water quality practices ranged between 20 and 40 percent (table 5.1) for the combined and six individual areas in this analysis.

The human capital variables had little impact on the use of water quality practices in the combined or individual areas. However, in the Susquehanna River Basin, farmers with a college education were more likely than farmers without a college education to adopt these practices. The importance of a college education in the Susquehanna area may be associated with the fact that only 14 percent of the farmers in the Susquehanna area had a college education, much less than in any other area by at least 20 percent. In the Mid-Columbia River Basin, more years of experience appeared to discourage the adoption of practices aimed primarily at protecting water quality.

The influence of farm size on adoption was not statistically significant for the combined-areas model. The Albemarle-Pamlico and White River areas were the only regions where farm size was positively related to the adoption of soil conservation practices to preserve water quality.

Cropping practices such as crop rotations, growing a row crop, and applying manure were positively and significantly associated with the adoption of water quality practices in the combined-areas model. The effect of crop rotations on the adoption of water quality practices were positive and significant in most individual areas. Only in the Mid-Columbia River Basin, where wheat is the chief crop grown in the area (65 percent of cropland acres) was the adoption of water quality practices more likely if a grain crop was grown.

Irrigation use, overall, was not a significant predictor of farmers' use of soil conservation practices, except in the Albemarle-Pamlico Drainage and the Mid-Columbia River Basin regions. In the Albemarle-Pamlico region, farmers who irrigated were more likely to adopt water quality practices. Alternatively, irrigators in the Mid-Columbia River Basin were less likely to adopt practices to preserve water quality. The Mid-Columbia River Basin is an area that is highly susceptible to wind erosion, so farmers may have had less need to adopt soil conservation practices that prevent soil from entering waterways.

Conservation compliance and technical assistance played important roles in farmers' use of water quality practices. Farmers subject to conservation compliance were more likely to make the extra investments in water quality practices, except in the Albemarle-Pamlico area. Farmers in the Albemarle-Pamlico region had very low erosion rates and very few producers were subject to compliance. Conservation compliance has a more significant influence on farmers' use of water quality practices than on their use of other soil conservation systems relative to other factors. Table 5.3 shows that the adoption rate for producers subject to conservation compliance was 25.7 percent compared with 15.2 percent for those not subject to conservation compliance.

Technical assistance also had a strong influence on farmers' use of water quality practices in most regions. Producers who developed a conservation plan with assistance from the Extension Service or Soil Conservation District had a 24 percent adoption rate compared with 10.7 percent for those who did not receive assistance. These results indicate that the compliance provisions and the availability of technical assistance significantly encourage the use of practices designed to provide off-site benefits.

The proximity of a field to a lake or a stream influenced a farmer's decision to adopt practices that are used for the sole purpose of preventing soil from entering waterways once it has migrated from the field for the combined areas and in the Albemarle-Pamlico and the Illinois/Iowa River Basin.

The natural resource variables defining soil quality, SLP and PISOIL did not significantly increase the probability of farmers' use of water quality practices except in Albemarle-Pamlico. However, in the Mid-Columbia and Susquehanna River Basins, the greater the productive capacity of soil, the lower the probability of adoption. This result could indicate that producers may not fully experience the impacts that erosion can have on soil productivity. Expanded nutrient use, for example, may have obscured any productivity losses from soil erosion.

The source of inherent erosion did explain some patterns of farmers' use of conservation practices. In the

water quality adoption models, erosion levels were separated into two erosion types, sheet and rill or rainfall (RKLS) and wind (WIND) erosion.[6] In the combined-areas model, inherent erosion due to rainfall increased the likelihood of farmers' use of conservation practices, and alternatively, inherent wind erosion reduced farmers' use of such practices. In the models for the Illinois/Iowa and Susquehanna River Basins, the higher inherent erosion from rainfall, the greater expected adoption. In the Central Nebraska and Illinois/Iowa Basins, higher wind erosion levels decreased the likelihood that a producer would make the extra investments in water quality practices. These outcomes are reasonable since the water quality practices are generally placed at the edge of fields or within channels, and would not be effective against wind erosion. Furthermore, sheet and rill erosion was greater on average for producers using water quality practices. Farmers with high sheet and rill erosion levels were significantly more likely to undertake extra investments to prevent soil from washing into waterways.

[6] In many areas, wind erosion was nonexistent and this variable was excluded from the estimation. RKLS was also omitted from some of the single-area models that had higher rates of wind erosion because this variable was highly correlated with the conservation compliance variable

The effects of RAIN and TEMP varied depending on the region. The higher the monthly rainfall in the Central Nebraska and the White River Basins, the more likely were producers to adopt water quality practices. However, higher rainfall levels discouraged adoption in the Illinois/Iowa River Basins.

Conservation Tillage

The third category of conservation practices that we analyzed was tillage. There have been many recent studies of farmers' use of reduced tillage, and many of these studies build on the work done by Rahm and Huffman (1984) on conservation tillage adoption in Iowa corn production. They found that use differed widely across farms due to soil characteristics, cropping systems, and the size of the farm. Norris and Batie (1987) found that the "factors influencing the adoption of conservation tillage are different from those which influence the decision to use other conservation practices." Tillage practices were combined into three groups: no-till, mulch- or ridge-till, and conventional tillage. The term "conservation tillage" typically includes the use of no-till, ridge-till, or mulch-till systems (see box, "Glossary of Soil Conservation Practices," p. 64). In the Area Studies survey, the designation of practices within the mulch- and ridge-till category relies on the farmer's judgment of how much crop residue was left on the ground after planting, and therefore, is not as clearly defined as the no-till or con-

Figure 5.6
Adoption of tillage practices by region

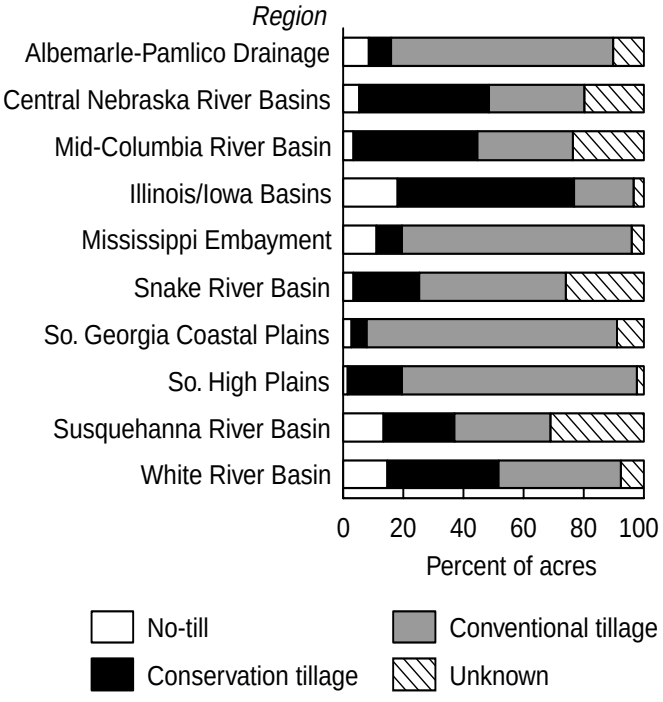
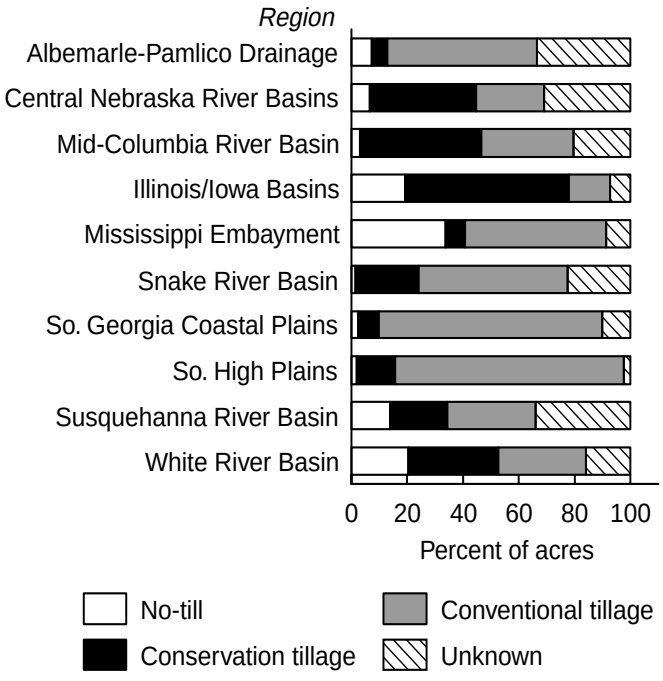


Figure 5.7
Adoption of tillage practices on highly erodible cropland by region



ventional tillage categories. Since no-till systems offer the best protection from soil erosion (i.e., the soil is broken only at seeding), it is considered separately in the model. Conventional tillage is defined as any tillage system, such as the use of a moldboard plow, that leaves less than 30 percent of the soil surface covered with crop residues after planting. Conventional tillage is assumed to afford the least protection against soil erosion. Sandretto (1997) presents a comprehensive summary of crop residue management issues.

Agricultural producers, seeking cost-effective technologies that maintain or increase crop productivity, will choose between alternative tillage technologies to substitute increasingly expensive resources for relatively less expensive ones. The adoption of no-till, for example, can reduce labor, energy, and machinery costs (Bull and Sandretto, 1996). However, the use of no-till has sometimes been associated with increased agricultural chemical costs resulting from increased weed populations. A farmer will likely adopt no-till if the cost savings, or benefits, outweighs any expected increases in chemical or management costs or reduction in crop revenue. In some cases, the feasibility of using certain tillage practices may be limited due to location-specific factors. For example, soil conditions may be such that the use of conventional tillage systems is necessary to prevent soil compaction, which can be detrimental to crop growth.

Table 5.5—Sample means from tillage adoption models

Variables	Combined areas	Illinois/Iowa Basins	Susquehanna River Basin	White River Basin
NO-TILL	.11	.19	.19	.16
MULCH- or RIDGE-TILL	.34	.60	.34	.40
CONVENTIONAL TILLAGE	.55	.21	.47	.44
COLLEGE	.45	.39	.13	.44
EXPERIENCE	24	25	22	25
WORKOFF	30	41	54	62
TENURE	.36	.37	.58	.39
ACRES	1631	921	466	958
ROTATION	.56	.84	.75	.82
ROWCROP	.84	.98	.83	.96
GRAIN	.16	.06	.32	.06
DBL-CROP	.05	.01	.05	.02
MANURE	.09	.19	.70	.10
IRRIGATION	.27	.02	.02	.00
COMPLY	.18	.13	.13	.11
CVPLAN	.55	.55	.51	.44
INSURE	.43	.65	.05	.18
WATERBODY	.43	.35	.18	.39
SLP	117	91	100	111
PISOIL	.81	.95	.69	.91
EROTON	32	26	54	24
RAIN	3.1	3.0	3.5	3.4
TEMP	55	50	51	52
Number of observations:	5746	1228	266	686

Refer to Chapter 2 for variable definitions and units.

Figure 5.6 shows tillage practice adoption by area, and figure 5.7 presents adoption on highly erodible cropland. For all the regions combined, 10 percent of highly erodible cropland is cultivated using no-till systems. Highly erodible cropland in the Mississippi Embayment, and the Illinois/Iowa, Susquehanna, and White River Basins had the highest proportion of acres devoted to no-till systems. Only between 1 and 3 percent of the highly erodible cropland in the Mid-Columbia and Snake River Basins, and the Southern Georgia Coastal and High Plains regions were under no-till production. Conventional tillage was applied on about 80 percent of the highly erodible cropland in the Southern Georgia Coastal and the Southern High Plains regions. For the remaining regions, less than 50 percent of the highly erodible cropland was cultivated using conventional tillage.

The sample means for the combined-areas and single-area models are presented in table 5.5. A multinomial logit model was estimated to determine the factors that affect farmers' use of tillage practices. The model results, along with the significance level, from the adoption study of tillage practices for the combined- and single-area models are displayed in tables 5.6 and 5.7. The analysis of the results focuses more on the effect of the exogenous variables on use of no-till and conventional tillage, since the mulch- and ridge-till category is less clearly defined and the results may be less informative.

For all areas combined, about 11 percent of farmers reported using no-till, 34 percent used mulch- or ridge-till, and 55 percent used conventional tillage. The percent of correct predictions was 67, and the pseudo R^2 was 0.44. The regions analyzed for the tillage adoption models included the Illinois/Iowa, Susquehanna, and White River Basins. These regions were the only areas with a sufficient number of observations for the no-till and conservation tillage categories. Furthermore, some variables were not included in the single regional models due to limited numbers of observations, little variation in the observations, or a high degree of correlation between independent vari-

ables. The individual regional results are displayed in table 5.7.

Education and the number of days the operator worked off the farm did not have a significant effect on the choice of tillage practice in the combined model, but a college education had a positive influence on the use of no-till in the Susquehanna and White River Basins. The number of days that an agricultural producer worked off-farm increased the probability of no-till adoption in the Illinois/Iowa Basins and mulch- or ridge-till in the Susquehanna River Basin. Land tenure, and to some degree, years of experience did have an effect on farmers' use of these tillage practices. Farmers who owned their land were more likely to use conventional tillage and less likely to use mulch- or ridge-till in the combined area and the White River Basin. Similar results were also observed in the models estimating adoption of *any* soil conservation practice. These results indicate that farm ownership is not a significant impediment for the adoption of conservation tillage systems. Farmers with many years of experience in farming were more likely to use mulch- or ridge-till in the combined sample and the White River Basin. Crop insurance had no impact on tillage choice except in the Illinois/Iowa Basin where farmers who had crop insurance were more likely to use no-till than those without crop insurance.

Table 5.6--Change in percent predicted adoption of tillage practices: Combined-areas model

Variables	No-till	Mulch-till/ ridge-till	Conventional tillage
CONSTANT	-2.0874**	-2.4508**	4.5382**
COLLEGE	0.0044	0.0170	-0.0214
EXPERIENCE	-0.0088	0.0266**	-0.0179
WORKOFF	0.0026*	-0.0001	-0.0025
TENURE	-0.0088	-0.0300**	0.0388**
ACRES	0.0155**	0.0295**	-0.0450**
ROTATION	0.0347**	0.0496**	-0.0843**
ROWCROP	-0.0443**	0.0401	0.0043
GRAIN	-0.0237	0.0620**	-0.0383
DBL-CROP	0.0483**	-0.0574	0.0091
MANURE	0.0242*	-0.0012	-0.0229
IRRIGATION	-0.0411**	0.0596**	-0.0185
COMPLY	0.0488**	0.0046	-0.0534**
CVPLAN	0.0364**	0.0118	-0.0482**
INSURE	0.0065	-0.0025	-0.0040
WATERBODY	-0.0035	0.0185	-0.0150
SLP	-0.0005	-0.0080	0.0085
PISOIL	0.0348	0.0435	-0.0783*
EROTON	0.0059	0.0084	-0.0143*
RAIN	0.1833**	-0.1067	-0.0767
TEMP	0.4155**	0.5553**	-0.9708**
% predicted adoption	9.4	30.2	60.3
Number of observations		5746	
% correct predictions		67	
Pseudo R^2 [1]		.44	

** Significant at the 5-percent level.
* Significant at the 10-percent level.
[1] Veall and Zimmerman's pseudo R^2.

Note: For the table, the coefficients estimated from the limited dependent model have been converted into change in percent predicted adoption. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, RKLS, WIND, RAIN AND TEMP), the reported value is the change in the percent predicted adoption given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in the percent predicted adoption with a unit change of 0.01 from the variable mean. See Appendixes 2-A and 2-B for further details.

The number of acres that a farmer operated had a significant and positive influence on the adoption of conservation tillage practices in all areas except the White River Basin. Farmers cultivating a large number of acres were more likely to use no-till or mulch- or ridge-till than those producing on few acres, and were less likely to use conventional tillage. As shown in table 5.3, 12.2 percent of farmers who cultivated at least 5,000 acres used no-till, compared with 8.6 percent of farmers who cultivated 500 acres or less in the combined sample.

The effect of cropping practices on tillage use varied, depending on the region. Only in the Illinois/Iowa Basins and combined-areas models did the probability of a farmer's use of no-till increase if the farmer was using crop rotations for pest or nutrient management. Agricultural producers in the Illinois/Iowa Basins were less likely to adopt no-till and more likely to adopt conventional tillage if they were cultivating grain. An unexpected result in the combined-area model was that farmers who cultivated row crops were less likely to adopt no-till and those who cultivated a grain were more likely to use mulch- or ridge-till. Producers may choose to not cultivate highly erosive crops and to use no-till simultaneously. Farmers who double-cropped had a higher probability of using no-till systems than those who mono-cropped. Bull and Sandretto (1996) also found that there was extensive use of no-till with double-cropping since no-till may reduce moisture loss from seedbeds as well as provide more flexible timing as to when to plant the second crop.

Whether or not a farmer applied manure to the field had differing impacts on the farmer's use of conservation tillage. In the Illinois/Iowa River Basins, manure applications increased the likelihood of no-till use.

However, in the White River Basin, farmers who applied manure were less likely to adopt no-till. Irrigators were less likely than nonirrigators to adopt no-till and more likely to use mulch- or ridge-till. Overall, the irrigated regions covered by the Area Studies survey did not have high use of no-till. One reason is that farmers may find it infeasible to apply no-till on cropland in conjunction with certain types of irrigation technologies.

Conservation compliance and technical assistance were important in encouraging the use of no-till. Table 5.3 illustrates how the adoption rate is expected to change with changes in conservation compliance and the development of a conservation plan for the combined sample. Predicted use of no-till by farmers who were subject to conservation compliance was 14.3 percent, compared with 8.6 percent by farmers not subject to compliance. Farmers who developed a conservation plan had a higher predicted no-till adoption rate than those who did not develop a conservation plan, 11.2 and 7.6 percent, respectively. Of the two policies, conservation compliance had the greater impact on no-till adoption. Farmers subject to conservation compliance were more likely to use no-till systems in the White River Basin, and less likely to use conventional tillage in the Illinois/Iowa and Susquehanna River Basins. The Susquehanna River Basin was the only region where having a conservation plan had no impact on farmers' use of tillage practices.

Natural resource characteristics played a very small role in influencing a farmer's choice of tillage practices. Field location near a water body and soil leaching potential had no effect on the choice of tillage practices, except in the White River Basin. Highly productive soils in the Susquehanna River Basin discouraged use of conventional tillage.

Table 5.7—Change in percent predicted adoption of tillage practices: Single-area models

	Illinois/Iowa River Basins			Susquehanna River Basin			White River Basin		
Variables	No-till	Mulch-till/ ridge-till	Conventional tillage	No-till	Mulch-till/ ridge-till	Conventional tillage	No-till	Mulch-till/ ridge-till	Conventional tillage
CONSTANT	-2.0393**	0.2604	1.7789**	0.6399	-1.1526	0.5127	0.0340	-1.4394**	1.0990*
COLLEGE	-0.0127	0.0372	-0.0246	0.1677**	-0.0680	-0.0997	0.0817**	-0.0531	-0.0286
EXPERIENCE	-0.0214	0.0325	-0.0112	0.0196	0.0700	-0.0896*	-0.0195	0.1044**	-0.0849**
WORKOFF	0.0156**	-0.0090	-0.0066	-0.0314*	0.0513**	-0.0199	0.0033	-0.0127	0.0093
TENURE	-0.0125	-0.0082	0.0209	-0.0866	-0.0009	0.0875	0.0028	-0.1007**	0.0979**
ACRES	0.0530**	0.0211	-0.0741**	0.0676**	0.1179**	-0.1855**	0.0144	0.0259	-0.0403*
ROTATION	0.0685**	-0.0387	-0.0299	0.0874	-0.1642**	0.0767	-0.0597*	0.1192**	-0.0595
GRAIN	-0.1153**	0.0107	0.1046**	0.0961*	-0.2814**	0.1853	0.0383	-0.1312	0.0929
MANURE	0.0674**	-0.0554	-0.0121	-0.0258	0.1694**	-0.1436*	-0.1301**	0.0379	0.0923
COMPLY	0.0294	0.0610	-0.0904**	0.0707	0.1968*	-0.2675**	0.1184**	-0.0607	-0.0577
CVPLAN	0.0851**	-0.0065	-0.0785**	0.0526	0.0210	-0.0736	0.0887**	-0.0477	-0.0411
INSURE	0.0607**	-0.0312	-0.0295	—	—	—	0.0466	0.0334	-0.0801
WATERBODY	-0.0114	0.0362	-0.0248	-0.0077	-0.0461	0.0538	0.0257	0.0615	-0.0873**
SLP	0.0621	-0.0403	-0.0218	-0.0914	-0.1088	0.2002	0.0584	0.2077**	-0.2661**
PISOIL	0.1331	-0.1836	0.0505	0.0930	0.2073	-0.3003**	-0.2137	-0.1758	0.3895
EROTON	—	—	—	0.0074	-0.0828**	0.0753*	0.0011	0.0177	-0.0182
RAIN	1.1606**	0.0648	-1.2254**	-1.0202	0.2297	0.7905	-0.3300	0.7604*	-0.4304
% predicted adoption	16.5	65.4	18.1	16.3	33.9	49.9	13.6	41.6	44.8
Number of observations		1228			266			686	
% correct predictions		60			63			52	
Pseudo R^2 [1]		.22			.40			.21	

— Variable not included in the adoption model.
** Significant at the 5-percent level.
* Significant at the 10-percentlevel.
[1] Veall and Zimmerman's pseudo R^2.

Note: For the table, the coefficients estimated from the limited dependent model have been converted into change in percent predicted adoption. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, RKLS, WIND, RAIN AND TEMP), the reported value is the change in the percent predicted adoption given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in the percent predicted adoption with a unit change of 0.01 from the variable mean. See Appendixes 2-A and 2-B for further details.

Temperature had a larger and more significant impact on tillage adoption decisions than rainfall in the combined-areas model. High average monthly temperatures and rainfall significantly encouraged use of no-till practices. However, high temperatures also increased the probability of adopting other conservation tillage methods and discouraged the adoption of conventional tillage. In the single-area models, climate influenced tillage adoption only in the Illinois/Iowa River Basins, where high levels of average rainfall encouraged the use of no-till and discouraged the use of conventional tillage systems.

Summary

The results from the combined-areas and single-area models varied depending on the region and/or soil conservation practice examined in the estimation. The human capital of a farmer (measured by education and experience), overall, did not have a significant influence on the use of soil conservation practices. Human capital did affect a farmer's use of tillage practices, however. Farmers who owned their land were less likely to adopt soil conservation practices for the combined areas, but was only statistically significant in 2 of the 8 individual areas we analyzed. This implies that landowners were no more likely to adopt soil-conserving practices than renters in the areas surveyed. This was particularly true for the use of conservation tillage practices. Since, however, the tenure question was asked with respect to only the field, the data probably do not support an adequate test of hypotheses about ownership and adoption.

Farm size and cropping practices affected the probability of a farmer's use of soil conservation and tillage practices. Larger farm sizes increased the probability that a farmer would adopt soil conservation practices. However, farm size was not a significant factor in determining adoption in regions that have larger farm sizes on average. Although farmers who operated larger farms were positively associated with no-till adoption, the regions that had a sufficient number of no-till observations for modeling adoption were those with low average farm sizes compared with other regions. Cropping practices, especially crop type and the use of crop rotations, were significant determinants of farmers' use of soil conservation practices. Climate also affected farmers' use of soil conservation practices. Higher average monthly rainfall and temperature levels were positively associated with soil conservation and tillage practices in many instances.

The strongest results were obtained for the influence of agricultural policies. Conservation compliance and technical assistance were positively associated with farmers' use of soil conservation and tillage practices, particularly for those practices with primarily off-site benefits. The likelihood of adoption was determined more by these factors than by natural resource characteristics. Natural resource endowments seemed to be more important in predicting the adoption of water quality practices than for *any* soil conservation or tillage practice.

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6. Water Management

In this chapter, we briefly describe water management issues and the technologies and practices associated with irrigation. The Area Studies survey data are described with respect to the use of irrigation practices. The results of simple adoption models for these practices are reported for the combined-areas and single-area models. The human capital, production, agricultural policy, natural resource, and climate factors affecting the adoption of water management practices are discussed.

Agricultural production can require extensive quantities of water, especially in arid regions where evapotranspiration rates are high. The relatively fixed amount of developed water supplies has contributed to increased competition between irrigated agriculture and other water demands, such as for municipal, industrial, and environmental uses. The challenge for the agricultural sector is to maintain productivity with a diminishing supply of water. More efficient irrigation technologies have been developed to conserve water, and such technologies will help producers meet this challenge.

The use of water for irrigation can have implications for the quality of both ground and surface water. Irrigation can accelerate the transport of soils off the fields and contribute to sediment loadings in surface water resources. Chemicals that adhere to soil particles are also transported into the water. Water drainage from irrigated agriculture can contain chemical contaminants that may run off fields directly into waterways or leach into groundwater (NRC, 1989). The National Research Council (1996) reported that in the arid Western States, irrigated cropland accounted for 89 percent of river and 40 percent of lake pollution from sediment and chemical runoff. The soil conditions that enhance the transport of chemicals are often the same that increase the need for water applications. Soils with low water-holding capacity, such as sandy soils, cannot retain water as readily as soils containing large amounts of clay, for example. These highly leachable soils can act like a sieve where water moves easily through soil particles transporting chemicals to water bodies.

Farmers' decisions whether or not to irrigate and the choice of irrigation system depend on many factors. Use of irrigation reduces the risks associated with variable climate and soil conditions, but installation of irrigation equipment often requires large capital investments. The effectiveness of an irrigation system is site specific and depends on the physical characteristics of the land on which it is used (Caswell and Zilberman, 1985; Negri and Brooks, 1990). Farmers will base their decision to invest in irrigation on whether the benefits of adoption outweigh expected costs, compared with their current production system. Whether or not supplemental water applications are needed for crop production depends on climate, crop requirements, and soil conditions. Water inputs in crop production may be necessary for soils that are highly leachable. Adoption decisions will also be based on field topography. The more uniform the contour of the land, the greater the efficiency of water applications (Caswell, 1991).

Summary of Water Management Practices and Data

The Area Studies survey sample contains a wide distribution of soil types and irrigation adoption rates. The sample design was not targeted to capture a representation of irrigated agriculture, however. Figure 6.1 displays the percent of cropland acres by soil leaching potential (SLP)[1] for each region. The measure of SLP was divided into three categories representing low, moderate, and highly leachable soils.[2] The areas with 40 percent or more cropland acres categorized as highly leachable soils were the Mid-Columbia and Snake River Basins, Southern Georgia Coastal Plains, Albemarle-Pamlico Drainage, Southern High Plains, and Mississippi Embayment.

Figure 6.2 displays the percent of irrigated cropland by highly leachable soils. The Snake River Basin had the largest amount of highly leachable acres under irrigation, almost 90 percent. The Central Nebraska River Basins area was the next highest with 50 percent of highly leachable acres under irrigation. The amount of residual water that transports chemicals to groundwater supplies or to surface water through subsurface flows

[1] Soil leaching potential measures the inherent potential of soil to leach chemicals into groundwater. SLP is described more fully in chapter 2.

[2] For figure 6.1, we also included a category for observations with unknown soil leaching potential.

Figure 6.1
Soil leaching potential by region

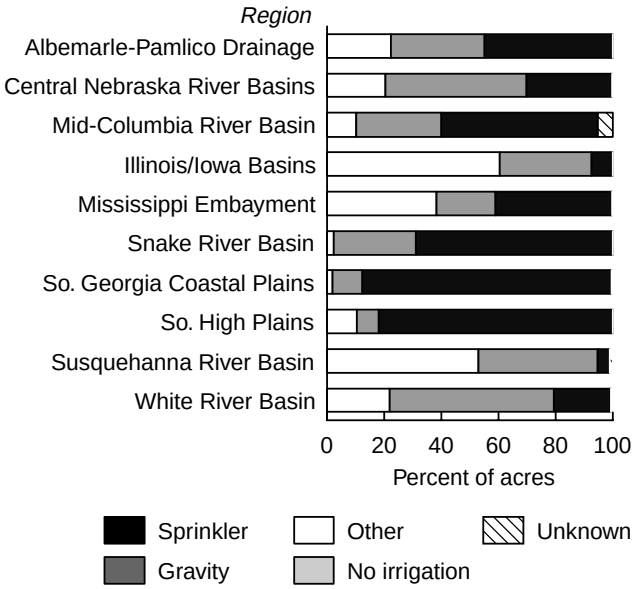
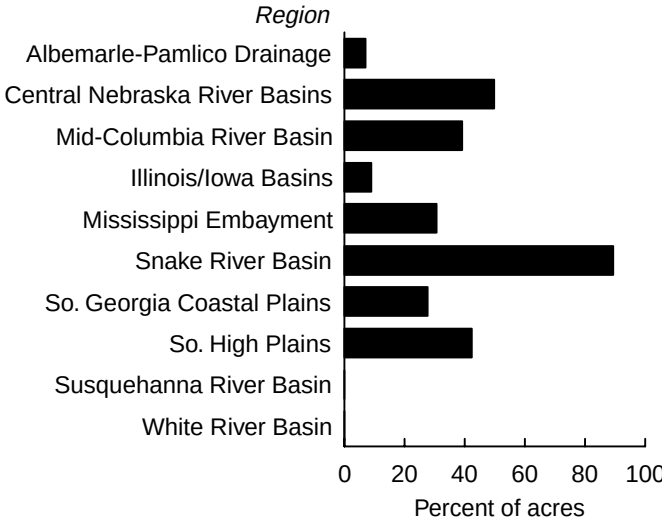


Figure 6.2
Adoption of any irrigation practice on highly leachable cropland by region



will depend on the quantity of water applied and the water-use efficiency of the irrigation system.

Irrigation technologies have been developed to provide more efficient management of water and energy resources. The performance of these irrigation technologies greatly depends on crop requirements, and soil and field conditions. Aillery and Gollehon (1997) offer a detailed description of different irrigation technologies and the advantages and disadvantages of each.

There are two broad categories of irrigation technologies, gravity versus pressurized systems. Gravity systems, as the name implies, operate with the use of gravity to transport water along furrows or across the surface of the field (basin). Gravity systems perform best on fields that have a uniform contour and higher quality soils, such as soils with low leaching potential. Pressurized systems, such as sprinklers or drip irrigation, depend on energy to distribute water to the crop. These systems generally distribute water more efficiently to plants than gravity systems do, and have a relative advantage on nonuniform fields with greater slopes and on soils with higher leaching potential. Although pressurized technologies require the use of energy and greater capital investments, there are savings in water use and potentially in labor costs, especially with the use of self-propelled sprinkler or computerized drip systems. In addition, fertilizers and other chemicals can be delivered through these systems with the irrigation water thereby reducing labor costs further. Figure 6.3 shows the distribution of sprinkler and gravity irrigation on highly leachable land. Sprinkler systems are in greater use than gravity systems on highly leachable soils in the surveyed areas. Pressurized technologies have become increasingly popular. Acreage under pressurized systems has increased from 37 percent of total irrigated acreage in 1979 to 50 percent in 1994 (Aillery and Gollehon, 1997).

Figures 6.4 and 6.5 show the percent of acres on which some form of irrigation is used, by crop and region. Several crop dummies (ROWCROP, GRAIN, FRTVEG, CORN, COTTON, POTATOES, HIGHVAL) were used in individual irrigation adoption models to capture the effects of crop choice. The natural resource characteristics included in the analyses were also expanded. The components of the aggregate erosion measure were included separately to reflect sheet and rill erosion (RKLS) and wind erosion (WIND). A variable (SLOPE) was included to reflect differences in irrigation technology effectiveness due to unlevel terrain. In addition, a variable (WATERBODY) was used to indicate whether the field was adjacent to a water body.[3] No ADVICE variable was included because the survey instrument did not ask about sources of information or technical assistance for water management.

The first (binomial) adoption model below focuses on the factors that determine the decision to irrigate, i.e.,

[3] Respondents were asked if the field was beside a stream, river, lake, pond, canal, or ditch.

Figure 6.3
Adoption of irrigation practices on highly leachable cropland by region

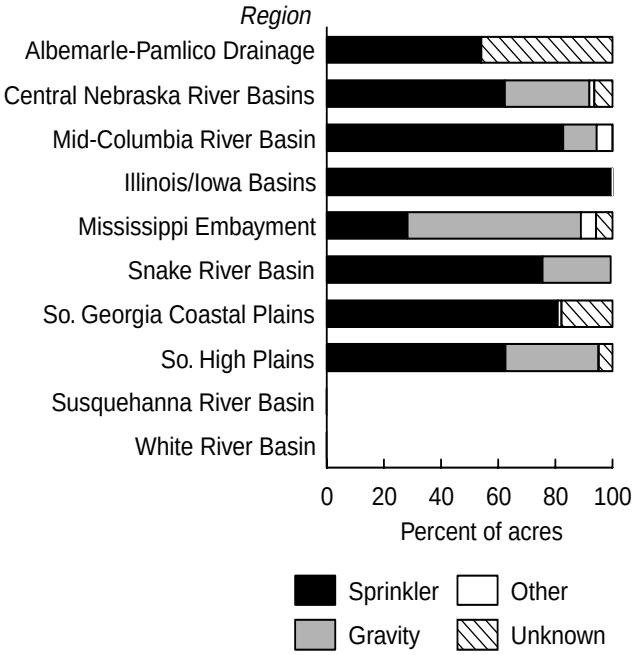


Figure 6.4
Decision to irrigate by crop

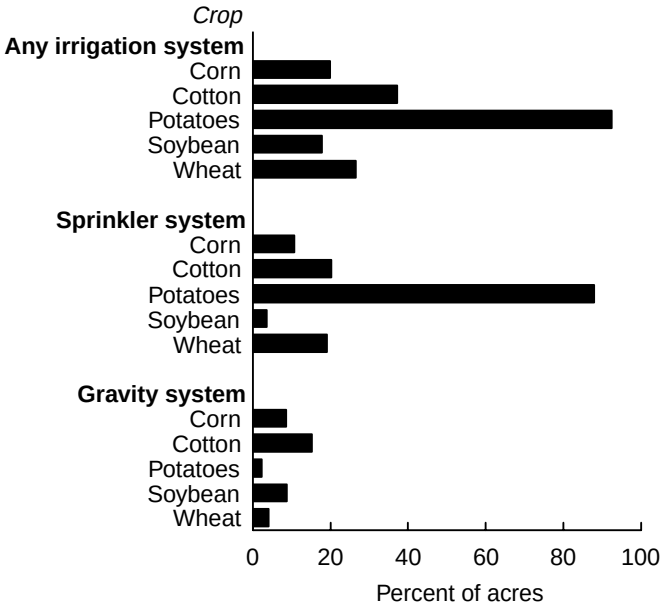
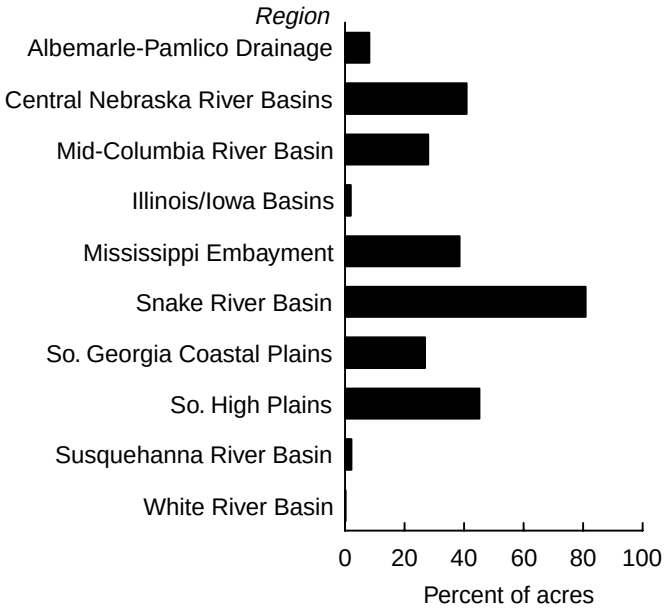


Figure 6.5
Decision to irrigate by region



whether any irrigation system is used. The irrigation practices included in this model are center pivot, sprinkler, gravity, drip and trickle, and subirrigation systems. The second (multinomial) adoption model provides estimates on the factors that influence the use of particular irrigation systems. In this model, three categories were created to examine decisions to 1) not irrigate; 2) use a sprinkler system[4]; and 3) use a gravity system. Gravity systems were separated from sprinkler systems since the underlying method for applying water, as well as the efficiency in applying water, differs. See box, pp. 80-81 for a detailed description on the types of irrigation systems covered in the analysis.

Adoption of Water Management Practices

Decision to Irrigate

The sample means for the combined regional and single-area models are presented in table 6.1. The regions chosen for analysis for the single-area adoption models were the Central Nebraska River Basins, the Mississippi Embayment, the Snake River Basin, the Southern Georgia Coastal Plain, and the Southern High Plains. For the regions investigated, the Snake River Basin had the highest actual irrigation adoption rate, 81 percent. The lowest irrigation adoption rate, 27 percent, was in the Southern Georgia Coastal Plain. The results, along with the significance level, from the irrigation adoption models are displayed in table 6.2. The econometric modeling framework and core set of variables are described in detail in chapter 2.

[4] Since very few producers reported using drip and trickle or subirrigation systems, these were not included as an additional category for analysis.

For the 10 combined areas, 26 percent of producers used irrigation in agricultural production. The predicted probability of adoption for the combined-areas model was 11.8 percent. The percent of correct predictions was 83 percent and the pseudo R^2 was 0.53.

Producer characteristics were important determinants of irrigation adoption in the combined-areas model, but the effects in the regional analyses varied. Farmers with at least some college level education (COLLEGE) were more likely to use irrigation practices in the combined areas, but only in the Mississippi Embayment was the likelihood of irrigation adoption significantly greater if the producer had a college education. Years of experience (EXPERIENCE) also had no significant effect on the probability of irrigation adoption in the single-area models, but in the combined sample, farmers with more years of farming experience were less likely to use irrigation. The more days that a farmer worked off of the farm (WORKOFF), the less likely he or she would adopt irrigation in the combined area, the Central Nebraska River Basins, the Southern Georgia Coastal Plain, and the Southern High Plains models. This result may reflect the management or labor intensiveness of irrigation use.

Land ownership (TENURE) was positively and significantly related to use of irrigation. Table 6.4 shows that the percent predicted adoption of irrigation increased from 10.8 to 13.4 percent if producers owned the observed field. Farmers who owned their farm were expected to be more likely than renters to make the large capital investments required for irrigation. Land tenure also had a positive and statistically significant effect on irrigation adoption in the Central Nebraska and Snake River Basins, and in the Southern Georgia Coastal Plain regions. This result was associated with areas where the percent of farmers owning their own land was higher than the average for all regions (see table 6.1).

Whether or not a producer had crop insurance (INSURE) did not influence farmers' use of irrigation in any of the models. The effect of farm size (ACRES) on irrigation adoption differed greatly by region. While, in most regions, the larger the number of acres operated, the less likely were producers to irrigate, the opposite result was found in the Southern Georgia Coastal Plain. Producers in the Southern Georgia Coastal Plain had lower farm sizes on average and lower irrigation adoption than the other regions.

Table 6.1—Sample means from irrigation adoption models

Variables	Combined areas	Central Nebraska	Mississippi Embayment	Snake River Basin	Southern Georgia Coastal Plains	Southern High Plains
DECISION TO IRRIGATE	.26	.41	.39	.81	.27	.45
COLLEGE	.44	.38	.47	.60	.39	.55
EXPERIENCE	24	24	23	21	25	23
WORKOFF	32	31	21	35	41	23
TENURE	.38	.43	.30	.62	.46	.36
ACRES	1701	1610	2331	2550	1495	1967
ROTATION	.54	.42	.27	.66	.71	.19
ROWCROP	.30[1]	.50[1]	.88	.13[2]	.15[3]	.75
GRAIN	.21	.25	.11	.72	.17	.27
FRTVEG	.01	0	.10[4]	0	.08	.64[5]
PROGRAM	.80	.75	.87	.47	.80	.92
INSURE	.40	.43	.14	.27	.32	.70
WATERBODY	.43	.27	.77	.34	.40	.07
SLP	119	125	116	150	148	151
PISOIL	.80	.85	.80	.82	.37	.69
SLOPE	2.6	3.8	1.0	3.0	2.6	0.9
RKLS	21	27	19	8	16	5
WIND	11	19	0	29	0	66
RAIN	3.1	2.1	4.3	1.2	4.2	1.6
TEMP	55	49	61	44	65	58
Number of observations	6543	701	820	537	507	507

[1] Corn only
[2] Potatoes only
[3] Cotton only
[4] Fruit, vegetables or rice only
[5] High-value crops only

Regions with very large farms may have experienced some irrigation adoption inefficiencies due to their large size. Although the number of acres operated in the combined-area model was a statistically significant determinant of irrigation adoption, table 6.4 indicates that predicted adoption levels decreased by only 1 percentage point for farmers that operated 5,000 acres compared with 500 acres.

Crop rotations (ROTATION) increased the likelihood that a farmer would use irrigation except in the Central Nebraska and Snake River Basins. In the Central Nebraska River Basins, crop rotations were negatively correlated with irrigation adoption. The type of crop grown greatly influenced the likelihood of irrigation adoption in each region. The crops that increased the probability of irrigation included corn in the Central Nebraska River Basins; fruits, vegetables and other high-valued crops in the combined areas, Mississippi Embayment, Southern Georgia Coastal Plain, and the Southern High Plains; potatoes in the Snake River Basin; and cotton in Southern Georgia Coastal Plain. Producers who grew corn (ROWCROP) also were more likely to adopt any irrigation practice in the combined, the Central Nebraska, and Snake River Basins areas. The strong effect revealed in the Central Nebraska River Basins area likely drove the result in the combined area.

Participation in a Federal commodity program or CRP (PROGRAM) positively affected the use of irrigation

Table 6.2—Change in percent predicted decision to irrigate

Variables	Combined areas	Central Nebraska	Mississippi Embayment	Snake River Basin	Southern Georgia Coastal Plains	Southern High Plains
CONSTANT	-1.6926**	-0.1848	-2.9419**	0.2640**	-1.8044**	2.7589**
COLLEGE	0.0406**	0.0190	0.1292**	-0.0086	0.0781*	0.0579
EXPERIENCE	-0.0167**	-0.0860*	0.0139	0.0077	-0.0673*	0.0113
WORKOFF	-0.0074**	-0.0298**	-0.0092	-0.0020	-0.0341**	-0.0206**
TENURE	0.0245**	0.1154**	-0.0578	0.0284**	0.1285**	-0.0206
ACRES	-0.0041**	-0.0375*	-0.0017	-0.0267**	0.0629**	-0.1610**
ROTATION	0.0684**	-0.1486**	0.3209**	0.0180	0.0960**	0.4655**
ROWCROP	0.0841**[1]	0.3488**[1]	—	0.1350**[2]	—	—
FRTVEG	0.2321**	—	0.8378**[3]	—	0.2475**[4]	0.1848**[4]
PROGRAM	0.0545**	0.1723**	0.2324**	-0.0150	-0.0268	0.0619
INSURE	0.0137	0.1126**	-0.0479	-0.0040	-0.1707**	-0.0196
WATERBODY	0.0205**	0.0985*	0.0241	0.0100	0.1791**	-0.3268**
SLP	0.0356**	0.3193**	0.1020	0.0239	0.0585	-0.8991**
PISOIL	0.0155	0.4850**	0.0144	-0.0104	0.1652*	0.1357
SLOPE	-0.0570**	-0.0962**	-0.2003**	-0.0344**	-0.0244	-0.0543
RKLS	0.0064	—	—	—	—	—
WIND	0.0070**	0.1271**	—	0.0651**	—	0.1138*
RAIN	-1.0072**	-0.9930**	—	-0.0676**	0.5564*	-1.1992**
TEMP	2.1025**	—	2.4663**	—	—	—
Number of observations	6543	701	820	537	507	507
% predicted adoption:	11.8	37.2	31.7	97.3	20.4	44.4
% correct predictions:	83	77	76	91	77	72
Pseudo R^2: [5]	.53	.46	.49	.76	.37	.37

— Variable not included in the adoption model.
** Significant at the 5-percent level.
* Significant at the 10-percent level.
[1] Corn only.
[2] Potatoes only.
[3] Fruit, vegetables, or rice only.
[4] High-value crops only.
[5] Veall and Zimmerman's pseudo R^2.

Note: For the table, the coefficients estimated from the limited dependent model have been converted into change in percent predicted adoption. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, RKLS, WIND, RAIN AND TEMP), the reported value is the change in the percent predicted adoption given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in the percent predicted adoption with a unit change of 0.01 from the variable mean. See Appendixes 2-A and 2-B for further details.

for the combined, the Central Nebraska River Basins, and the Mississippi Embayment areas.

Natural resource endowments of the field can determine the effectiveness and feasibility of irrigation. The only natural resource characteristics that appeared to play no role in irrigation adoption decisions were soil productivity (PISOIL) and soil erosion due to rainfall (RKLS). Producers who had fields adjacent to a water body (WATERBODY) were more likely to irrigate. One reason could be that the water body served as a water source for irrigation, but the data do not allow us to check whether that was the case.

In the combined-areas model, soil leaching potential (SLP) also had a significant and positive influence on use of irrigation. However, in the separate regions this was not the case, except in the Central Nebraska River Basins. In fact, soil leaching potential had the opposite effect in the Southern High Plains region. High SLP values usually signify the presence of sandy soils. The water retention capabilities of these soils are often limited, and crop production may require irrigation. The soil conditions that promote water applications are often the same conditions that convey chemicals into waterways, however. When making an irrigation decision, a producer considers the water-holding capacity of the soil and not necessarily whether chemicals will be transported. Therefore, a more direct measure of water-holding capacity may be better for assessing the impact of field characteristics on the adoption decision (*production impact*). The soil index, SLP, could be used to assess the potential fate and transport of water and chemicals associated with a particular adoption choice (*environmental impact*).

Table 6.3—Change in percent predicted adoption by irrigation type: Central Nebraska River Basins, Mississippi Embayment, Snake River Basin, and Southern High Plains Regions

Variables	Variable means	Non-irrigators	Sprinkler system	Gravity system
CONSTANT	—	3.7348**	-1.4592**	-2.2756**
COLLEGE	.47	-0.1036**	0.0654**	0.0383**
EXPERIENCE	23	-0.0111	-0.0038	-0.0073
WORKOFF	25	0.0115**	-0.0104**	-0.0010
TENURE	.36	-0.0282	0.0485**	-0.0203
ACRES	2084	0.0133*	0.0006	-0.0138**
ROTATION	.31	-0.1293**	0.0720**	0.0573**
CORN	.18	-0.3103**	0.2322**	0.0781**
COTTON	.27	-0.1153**	0.1834**	-0.0681**
POTATOES	.01	-0.5333	0.5839**	-0.0506
HIGHVAL[1]	.02	-0.3883**	0.3653**	0.0230
PROGRAM	.81	-0.1126**	0.0383	0.0743**
INSURE	.34	-0.0404	-0.0008	0.0412**
WATERBODY	.47	-0.0056	-0.0126	0.0182
SLP	129	-0.1151**	0.1417**	-0.0265
PISOIL	.79	-0.1310**	-0.0736	0.2046**
SLOPE	1.9	0.1268**	-0.0009	-0.1259**
WIND	20	0.0005	0.0252**	-0.0257**
RAIN	3.0	2.4738**	-1.0430**	-1.4307**
TEMP	56	-5.4925**	2.0744**	3.4182**
Mean of dependent variable		.59	.20	.21
Number of observations			2493	
% predicted adoption:		70.0	19.7	10.3
% correct predictions:			69	
Pseudo R^2: [2]			.53	

** Significant at the 5-percent level.
* Significant at the 10-percent level.
[1] High-value crops other than cotton.
[2] Veall and Zimmerman's pseudo R^2.

Note: For the table, the coefficients estimated from the limited dependent model have been converted into change in percent predicted adoption. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, RKLS, WIND, RAIN AND TEMP), the reported value is the change in the percent predicted adoption given a one-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in the percent predicted adoption with a unit change of 0.01 from the variable mean. See Appendixes 2-A and 2-B for further details.

Table 6.4—Percent predicted adoption: Combined areas

		Multinomial logit model		
Variables	Decision to irrigate	Non-irrigators	Pivot/sprinkler system	Gravity system
Probabilities at means	11.8	70.0	19.7	10.3
Land tenure	**		**	
Yes	13.4	68.0	23.0	9.0
No	10.8	70.9	18.0	11.1
Land operated	**			**
500 acres	12.0	68.9	19.7	11.4
5000 acres	11.0	71.7	19.8	8.5
Soil leaching potential	**	**	**	
100	11.2	72.4	16.7	10.9
150	12.7	68.0	22.2	9.9
Soil productivity		**		**
.50	11.2	73.1	22.1	4.8
.95	12.0	66.7	18.1	15.1
Slope	**	**		**
1.00	15.7	62.9	19.3	17.8
2.50	—	73.7	19.5	6.8
4.00	9.0	—	—	—

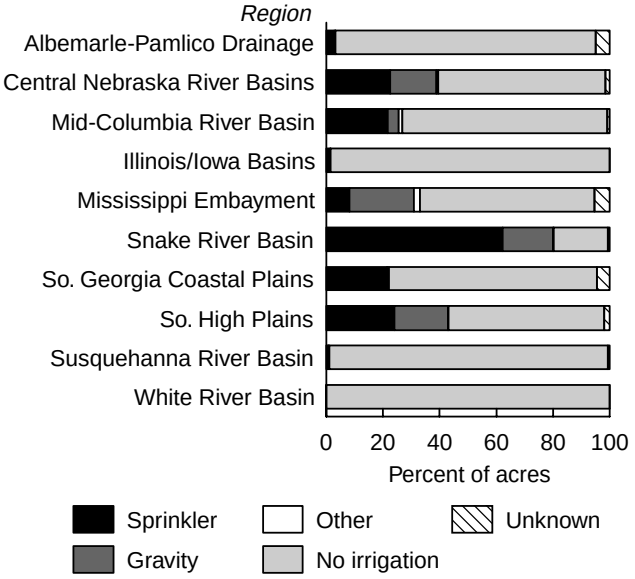
** Significant at the 5-percent level.
* Significant at the 10-percent level.

The probability that a producer would adopt irrigation was negatively influenced by land slope (SLOPE). The larger the degree of the slope, the less likely a producer would irrigate in the combined areas, the Central Nebraska River Basins, Mississippi Embayment, and Snake River Basin regions. Table 6.4 illustrates that a decrease in slope by 1 percent raised the percent predicted adoption to 15.7 compared with 11.8 percent when the percent slope is at its mean of 2.6 for the combined-areas sample.

Although soil erosion from rainfall did not affect farmers' use of irrigation, soil erosion due to wind did influence adoption as predicted. The greater the severity of the wind erosion problem, the more likely a producer would use irrigation. Wind erosion is mostly a problem in arid areas, and producers may wet the soil as a method for controlling wind erosion (WIND) in addition to providing water to crops.

The climate variables were the most important factors in determining the use of irrigation practices in the combined-areas model. Generally, producers in regions with low average rainfall (RAIN) and high

Figure 6.6
Adoption of irrigation practices by region



Glossary of Irrigation Practices

Sprinkler Systems

Center-Pivot System is a self-propelled electronic or hydraulic continuous move sprinkler or spray nozzle system that travels around a center pivot point. The pattern irrigated is essentially a circle. The unit can be end-towed from one field to another. The system is generally low pressure.

Hand-Move System consists of a portable aluminum pipe which must be moved one or more times per day to meet crop irrigation requirements.

Solid-Set consists of a portable aluminum pipe system that is placed in the field at the start of the irrigation season and left in place throughout the season.

Permanent Sprinkler System is a buried pipe system with only the risers and sprinklers above ground.

Lateral Move System is a self-propelled continuous move side-roll system on towers. It is designed to be used on square fields (1,320 ft. sq.) and on crops up to 9 ft. high. Water is supplied to the unit by a flexible rubber hose. The unit can be end-towed from one field to another.

Side Roll/Wheel Move System is a wheel-move lateral line, designed to be used on rectangular or square fields and on low-growing crops 4 feet high or less. The unit is moved by a small gasoline engine. The unit must be disassembled to move it from one field to another.

Side Roll/Wheel Move with Tow Lines System is a wheel-move lateral line with tow lines trailing behind the main lateral line, with one to three sprinklers per tow line. The unit is moved by a small gasoline engine. It can be used for crops up to 9 feet in length.

End-Tow System consists of an aluminum pipe sprinkler laterally mounted on dolly wheels or skids. The unit is end-towed through the field from one position to another by a tractor. It is designed to be used on hay and pasture crops, but can be used on some row and tree crops.

Carousel Sprinkler-Traveler is a system with a rotating boom that sprinkles or sprays water as it is propelled forward across a field. Its water supply comes from either a well or supply ditch. Most systems are self-propelled with a mounted gas or diesel engine.

Self-Propelled Gun Traveler System is self-propelled by a separate engine, or hydraulic continuous move. It consists of a single large gun mounted on a four wheel trailer. Water is supplied through a flexible rubber hose.

Reel-Type Hose Pull System uses a non-collapsible (hard) hose on a reel. The gun type sprinkler attaches to the hose and is stationed at one end of the field and the hose reel at

average temperatures (TEMP) were more likely to irrigate. Small changes in rainfall and temperature had a dramatic effect on adoption rates. In the Southern Georgia Coastal Plain, however, higher rainfall encouraged greater irrigation adoption. This result could indicate that climate variability may be more important in Georgia than actual average monthly rainfall. If rainfall is highly variable in this region, producers may be relying on irrigation to reduce risks associated with this variability. In this case, irrigation may be a risk management tool rather than a production necessity.

Choice of Irrigation Practices

In the multinomial model, three categories of irrigation practices were created for examining the adoption decisions of producers who 1) do not irrigate, 2) use a sprinkler system, or 3) use a gravity system. Gravity systems can be considered as a traditional irrigation system, and sprinkler represents more modern technology (Aillery and Gollehon, 1997). Figure 6.6 shows the percent of acreage on which each system is used in each region. The Central Nebraska River Basins, the Mississippi Embayment, the Snake River Basin and the Southern High Plains were the regions selected for a combined analysis of farmers' use of irrigation practices. These regions were chosen because they had a sufficient number of observations in each irrigation category. Table 6.3 presents the sample means and results along with the percent predicted adoption, percent correct predictions, and the pseudo R^2 for the model.

The results of the multinomial model for the "do not irrigate" choice generally are the same as for the binomial model, so will not be discussed further.

When a farmer worked off-farm much of the time, the probability of the farmer's using a sprinkler system was significantly lowered. However, off-farm work did not affect farmers' use of gravity systems. Sprinkler systems often require more labor and management than gravity systems. Therefore, that producers who worked more days off-farm may be more likely to invest in irrigation systems that have lower labor demands. Farmers who had crop insurance were more likely to adopt a gravity system.

Glossary (continued)

the other. As the water passes through the hose it activates a turbine drive system that rolls the hose onto the reel and pulls the sprinkler gun and carriage across the field, ready for the next move.

Reel-Type Cable Pull System is similar to the hose pull systems except the sprinkler gun and carriage are pulled by a cable as the hose is dragged in a loop across the field. These systems often require a grassed strip to operate on.

Gravity Systems

Gated Pipe System is a pipe, usually plastic (PVC) or aluminum, that is fitted with spaced closeable gates or holes that permit the water to flow into furrows or basins. For flood irrigation, the regulating gates are usually controlled manually but can be automated. This system usually requires a powered pumping system but can flow with gravity from a reservoir or diversion dam.

Gated Pipe with Surge Control is a modified gated pipe system in which a surge control valve alternates water delivery through two sets of gated pipe to provide water to the furrows in timed surges.

Open Ditch System is a method of irrigation where the water supply runs across the upper end of the field. The ditch gates transfer water from the ditch into the furrow.

Siphon Tubes are short tubes usually made of aluminum or plastic which are used to "siphon" water from a ditch into a furrow or field.

Cablegation is a modified gated pipe system which uses a moving plug attached by a cable inside the pipe to deliver water sequentially to furrows.

Other Irrigation Systems

Drip or Trickle is an irrigation method that requires maintenance of an adequate portion of the root zone of the plant at, or close to, full soil moisture capacity during the growing or productive cycle. Water is supplied through emitters attached to a supply pipe or porous tubing. The system is designed to be operated daily or at rather frequent intervals.

Subirrigation involves maintenance of the water table at some predetermined depth below the surface through the use of ditches, sub-surface drainage tubing or mole drains and water control structures. Conditions for use of this system are limited. The subirrigation system also serves as a drainage system. A good water supply is needed to supply irrigation water needs rapidly.

Source: U.S. Department of Agriculture, Economic Research Service and National Agricultural Statistics Service, Area Studies Interviewer's Manual.

Land tenure had a positive and significant effect on the adoption of sprinkler systems only. Table 6.4 shows that percent predicted adoption of sprinkler technologies increased from 18 to 23 percent for producers who owned the observed field. This outcome may reflect the greater capital investments often required for sprinkler irrigation technologies. Producers who own their farmland may be more likely than renters to make long-term investments.

While the number of acres operated did not have an effect on the use of sprinkler systems, producers with larger farms were less likely to use a gravity system. However, table 6.4 indicates that percent predicted adoption of gravity irrigation decreased by about 3 percentage points for farmers who operated 5,000 acres instead of 500 acres.

Cropping practices and the type of crop grown greatly influenced the use of irrigation practices. Crop rotations significantly increased farmers' use of both sprinkler and gravity systems. Producers growing corn, potatoes, cotton, or high-value crops were more likely to adopt sprinkler systems than if they grew grains or other field crops. Farmers who participated in commodity programs were more likely to adopt a gravity system than those who did not.

Soil and field conditions were important factors affecting the selection of irrigation practices. Table 6.4 shows how percent predicted adoption changes with changes in soil leaching potential, soil productivity, and field slope. Center pivot or other sprinkler systems were more likely to be used on soils with higher leaching potential, whereas gravity systems were more likely to be used on highly productive soils, which generally have higher water retention capabilities. The probability of using gravity systems increases for fields with a higher slope. Fields with higher wind erosion levels were more likely to be irrigated with a sprinkler system and less likely to be irrigated using a gravity system.

Climate played a major role in irrigation adoption. Low average rainfall and high temperatures increased the probability of adoption of both sprinkler and gravity systems.

Summary

Overall, the most significant factors that influenced the adoption of irrigation as well as irrigation technology choice were human capital, land tenure, the type of crop grown, and climate conditions. Farm size and natural resource characteristics were important in determining adoption in the combined and single regions that were analyzed.

Producers with a college education and those who owned the field were more likely than others to invest in irrigation technology. Conversely, the more days the producer worked off the farm, the greater the probability the producer chose not to irrigate. The probability of irrigation increases for producers growing cotton, potatoes, or other high-value crops. Percent predicted adoption also increased if a producer was growing corn. The prevalence of irrigated corn in the Central Nebraska Basin may have overshadowed the effects in other regions in the aggregate analysis.

The effect of farm size on irrigation use was mixed. Larger farms were less likely to use irrigation in the Snake River Basin, the Southern High Plains and in all 10 areas combined. Farm size had no effect on use of irrigation in the other regions. The results seem to suggest that larger farms may often be less able to adopt irrigation as efficiently as smaller farms. Furthermore, larger farms were less likely to adopt gravity systems. This could reflect the higher land preparation, energy, and water costs associated with gravity systems.

Of the resource characteristics, the slope of the field had a significant effect on irrigation adoption decisions. The greater the slope of the field, the less likely a producer would irrigate. However, in the multinomial choice model, field slope had no effect on the adoption of sprinkler systems, but was significant in deterring the use of gravity systems. Gravity systems are less adapted to nonuniform fields than sprinkler systems. Wind erosion also influenced irrigation adoption. Producers with fields subject to wind erosion were more likely to apply water, possibly reflecting efforts to control damages from soil erosion due to wind. Producers with fields that had higher soil erosion levels from wind were more likely to use sprinkler systems and less likely to use a gravity system. Soil leaching potential also had a significant effect on the choice of irrigation systems.

Finally, as expected, weather conditions played the greatest role in determining irrigation adoption decisions. In almost all regions, producers in hot and dry areas had a higher probability of applying water. The only region that had an inconsistent result was the Southern Georgia Coastal Plain, where producers were more likely to irrigate despite their high rainfall. This could indicate that producers may be using irrigation to control for climate variability, which our weather data do not reflect.

These results show that the strength of an Area Studies-type survey is in the analysis of region- and technology-specific characteristics affecting adoption. Generic indices may mask important factors. For the study of irrigation, the use of slope and wind erosion potential measures may be more illuminating than the composite erosion index used for the other studies.

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7. Adoption Impacts on Crop Yields and Chemical Use

In this chapter, we use individual cases from the Area Studies survey data to study the impact of technology adoption on crop yields and chemical use. The case study approach was necessary because results vary widely among crops, locations, and technologies so that an aggregate analysis was not feasible. The analysis is not comprehensive or exhaustive, but rather is offered to provide insights into the types of investigations that can be performed within a given framework.

The following section describes the econometric framework used to assess the impact of technology adoption on yields and chemical input use. The rest of the chapter describes the results of the models of pest, nutrient, soil, and irrigation management adoption impacts.

Econometric Framework

The effects of technology use on use of chemicals and productivity are difficult to assess because we observe farm production in a single time period only. Ideally, we would like information about farm production, economic conditions, and policies both before and after technology adoption in order to measure the causes and effects of technology use. Using only a single observation in time, we measure these factors by comparing adopters to nonadopters, which introduces a potential for errors because of *sample self-selection bias*, i.e., the sample of adopters is not random, farmers who use new technology may differ in systematic ways from farmers who do not. A simple comparison of agricultural chemical use among adopters and nonadopters may not reveal the full effects of technology choice.

Consider an example of self-selection bias. If the sample includes farms located in a microenvironment with unusually severe and common pest outbreaks, farmers there might apply above average amounts of pesticides to control these outbreaks. Because of their high pesticide costs, the farmers may use alternative pest-management strategies, such as integrated pest management (IPM). These producers can be expected to have an above-average rate of IPM adoption. Although IPM adoption might decrease their pesticide applications, they might use more pesticides than does an average farmer outside the microenvironment. If resource variables fail to include a microenvironment's climate conditions, then a correlation of IPM adoption and increased pesticide use is incorrect. IPM adopters, on average, use more pesticides than do nonadopters, although IPM use may reduce pesticide applications by farmers in the microenvironment.

The econometric approach deals with the self-selection problem with a model of the adoption decision and the input demand and crop supply decisions in a recursive framework (Fuglie and Bosch, 1995; Maddala, 1983). This approach takes into account possible systematic differences between adopters and nonadopters in order to evaluate the effects of technology adoption on input use and crop yield. Appendix 7-A provides details of the binomial and multinomial models that we used in the analysis. In order to correct for the possibility of simultaneous adoption and input decisions, the predicted value of adoption obtained from the logit estimation is used as an instrumental variable in the OLS estimations of input use and yield.

Results of the estimations presented as elasticities allow intuitive interpretations (see appendix 7-B for a full description). For example, the elasticity e_{YM} represents the percent change in yield, Y, resulting from a 1-percent change in the probability of adoption, M. Factors that affect both adoption and input use/yield are assessed also with the elasticity concept. The factor can affect input use/yield both directly and indirectly through a change in the probability of adoption. For example, suppose that large farms use chemical inputs more intensively and are more likely to adopt new technology than are small farms other things being equal. The total effect of an increase in farm size on chemical input use is the sum of these two effects: the direct effect (measured by the coefficient of the farm-size variable in the input demand equation) and the indirect effect through technology adoption (the product of the effect of farm size on technology adoption and of technology adoption on input demand). If new technology reduced chemical use, then the direct effect of an increase in farm size is increased chemical use. The indirect effect of technology adoption is to reduce chemical use. The net effect of an increase in farm size on chemical input use depends on which effect is the larger of the two.

Input demand and crop yield were modeled as functions of farmers' characteristics, cropping practices, policy attributes, resource endowments, and technolo-

gy adoption.[1] Pesticide demand was quantified as pounds of active ingredients per acre, a crude measure of pesticide use since it does not incorporate persistence in and risk to the environment. However, the amount of active ingredients applied does provide some indication of potential risks associated with increased use. Finally, nitrogen applications were measured in pounds per acre, and crop yields were measured in pounds per acre harvested. All variables used in the model are defined in chapter 2 and summarized in table 2.2.

Effects of Soil Conservation Practices on Chemical Use and Crop Yield

The use of soil conservation practices has been promoted to reduce erosion and decrease the movement of chemicals into waterways. However, some of these same practices may also increase the use of chemicals. For example, crop residue management systems, such as no-till, may increase insect and weed infestations, which might lead to a rise in pesticide applications. It has been argued, however, that chemical use may increase only in the short term and might decrease over time as producers become accustomed to a new soil management system.

We analyzed two case studies about technology adoption decisions and how soil conservation practices affected chemical applications and crop yields. Data limitations precluded analysis across all areas and crops. The first case study assesses how the adoption of tillage practices by soybean producers affects input demand and crop yield in the Albemarle-Pamlico Drainage, Southern Georgia Coastal Plain, Illinois/Iowa River Basins, Mississippi Embayment, and Central Nebraska River Basins.[2] The second case study examines soil conservation practices used to protect water quality by corn producers in the Central Nebraska, Illinois/Iowa, and White River Basins. Since pesticide and nutrient requirements are often crop-specific, the case studies were divided by crop in order to highlight differences in chemical demand and crop productivity among crops.

Soybeans in the Albemarle-Pamlico Drainage, Southern Georgia Coastal Plain, Illinois/Iowa River Basins, Mississippi Embayment, and Central Nebraska River Basins

Table 7.1 presents the sample means and the number of observations for soybean producers in the Albemarle-Pamlico Drainage, Southern Georgia Coastal Plain, Illinois/Iowa River Basins, Mississippi Embayment, and Central Nebraska River Basins. The change in percent predicted adoption is presented in table 7.2. Producers were separated into three adoption categories; 1) producers who used a no-till system; 2) producers who used other conservation tillage systems; and 3) producers who used conventional tillage systems. Of the chosen sample of soybean producers, 15 percent practiced no-till, 34 percent used

Table 7.1—Sample means from tillage adoption models for soybean producers in Albemarle-Pamlico Drainage, Southern Georgia Coastal Plain, Illinois/Iowa River Basins, Mississippi Embayment, and Central Nebraska River Basins

Variables	Means
NO-TILL	.15
MULCH- or RIDGE-TILL	.34
CONVENTIONAL TILLAGE	.51
COLLEGE	.42
EXPERIENCE	24
WORKOFF	33
TENURE	.32
ACRES	1532
ROTATION	.66
MANURE	.08
IRRIGATION	.18
COMPLY	.09
CVPLAN	.44
INSURE	.36
WATERBODY	.53
SLP	105
PISOIL	.84
EROTON	21
RAIN	3.5
TEMP	55
Number of observations	1683

[1] Area dummy variables were included in the model to account for regional variations, such as differences in prices, policies, incremental weather conditions, or pest infestation levels that may not be covered by the explanatory variables. The results were not presented in the tables, because regional coefficients are meaningful only if compared to the reference region.

[2] Fuglie (1999) analyzed the adoption of tillage practices for corn in the Corn Belt areas of the Area Studies survey area. He looked at the effects of tillage adoption on pesticide and fertilizer use and on crop yields. The results were so similar to what would have been presented here, we will not describe our analysis but will report Fuglie's results in the discussion.

either mulch- or ridge-till, and 51 percent used conventional tillage methods.

The results of the adoption models are generally consistent with those obtained from the tillage choice model reported in chapter 5 (see table 5.6). Soybean producers with larger farm size had a significantly higher probability of using no-till practices and had a lower probability of using conventional tillage systems than smaller-acreage farms. Conservation policies significantly fostered the use of no-till systems and discouraged the use of conventional tillage methods. Producers who were subject to conservation compliance or received technical assistance had a higher probability of using no-till and a lower probability of using conventional-tillage methods. At higher erosion levels, however, the probability of no-till use decreased for soybeans. We have no direct, empirical evidence about the cause of that result.

The adoption results were used in the second modeling stage to assess the effects of technology choice on chemical input use and yield. The estimates of input demand and crop yield effects for soybean producers and the R^2 from the models are presented in table 7.3. The elasticity estimates are presented in table 7.4, and they show the percent change in the dependent variable given a 1-percent change in the mean of the regressors. The probability of no-till adoption was the reference variable for the mulch- and ridge-till and conventional tillage variables.

Model results indicate that the tillage practice used did not have a significant effect on the amount of herbicides applied by soybean producers. Fuglie (1999)

Table 7.2—Predicted adoption by tillage practice for soybean producers in Albemarle-Pamlico Drainage, Southern Georgia Coastal Plain, Illinois/Iowa River Basins, Mississippi Embayment, and Central Nebraska River Basins

Variables	No-till	Mulch-till/ ridge-till	Conventional tillage
CONSTANT	-1.7831	-6.4993**	8.2824**
COLLEGE	0.0005	-0.0253	0.0248
EXPERIENCE	-0.0611**	0.0054	0.0557*
WORKOFF	0.0029	-0.0007	-0.0021
TENURE	-0.0039	-0.0410	0.0449
ACRES	0.0392**	0.0013	-0.0405**
ROTATION	-0.0681**	0.0785**	-0.0103
MANURE	0.1048**	0.0477	-0.1524**
IRRIGATION	-0.0399	0.1432**	-0.1032**
COMPLY	0.1297**	0.0139	-0.1436**
CVPLAN	0.0985**	0.0009	-0.0994**
INSURE	0.0049	-0.0165	0.0116
WATERBODY	-0.0267	0.0349	-0.0082
SLP	0.0163	0.0439	-0.0602
PISOIL	0.0049	-0.0321	0.0272
EROTON	-0.0225**	0.0026	0.0199
RAIN	0.9723**	-0.6869	-0.2854
TEMP	0.0638	1.8451**	-1.9090*
Mean of dependent variable	0.15	0.34	0.51
Percent predicted adoption	15.5	30.1	54.4
Percent correct predictions		66	
Pseudo R^2 [1]		0.49	

* Significant at the 10-percent level.
** Significant at the 5-percent level.
[1] Veall and Zimmerman's pseudo R^2.

Note: For the table, the coefficients estimated from the limited dependent model have been converted into change in percent predicted adoption. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, RKLS, WIND, RAIN AND TEMP), the reported value is the change in the percent predicted adoption given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in the percent predicted adoption with a unit change of 0.01 from the variable mean. See Appendixes 2-A and 2-B for further details.

Table 7.3—Estimates of input demand and crop yield effects for soybean producers in Albemarle-Pamlico Drainage, Southern Georgia Coastal Plain, Illinois/Iowa River Basins, Mississippi Embayment, and Central Nebraska River Basins—Tillage adoption

Variables	Herbicide use	Crop yield
	lbs/acre	
CONSTANT	-0.7967	4507.7**
COLLEGE	0.0994**	35.111
EXPERIENCE	0.0002	-2.4879*
WORKOFF	-0.0005	-0.6302**
TENURE	-0.0206	6.2437
ACRES	0.0181	71.621**
ROTATION	0.0785	160.90**
DBL_CROP	—	-164.71**
IRRIGATION	—	292.89**
ADVICE/INFO	0.0700	—
PROGRAM	0.0400	-40.883
INSURE	-0.0510	-68.206**
WATERBODY	0.0692	13.317
SLP	0.0004	-0.4516
PISOIL	0.3464*	559.40**
EROTON	-0.0015**	-2.7373**
RAIN	1.2489**	44.797
TEMP	—	-58.132**
PROB(CONSERVATION)	-0.1110	115.67
PROB(CONVENTIONAL)	-0.0894	-156.47
Mean of dependent	1.11	2174
Adjusted R^2	0.019	0.467

* Significant at the 10-percent level.
** Significant at the 5-percent level.

found, however, that the increased probability of no-till use by corn producers actually reduced herbicide applications. In our model, high erosion rates were associated with decreased herbicide applications. Conversely, herbicide applications were elevated in higher rainfall areas.

The choice of tillage practice also had no significant effect on crop yields for soybean producers in the Area Studies sample, but the probability of adopting a conservation tillage method had a negative effect on corn yields in the Fuglie model. The greater the years of experience and the greater number of days a producer worked off the farm were associated with decreased soybean yields per acre. Farm size and cropping practices also had a significant effect on soybean yields. Producers who operated larger farms, rotated crops, or irrigated the field had significantly higher crop yields. On the other hand, producers who double-cropped experienced lower yields. Yields were also less for producers with crop insurance.

Crop productivity varied depending on natural resource endowments of the field and weather conditions. Soil quality had a large influence on soybean yields. The elasticity estimates in table 7.4 show that soybean yields increased about 0.22 percent given a 1-percent change in the soil productivity index. Furthermore, increased erosion levels on the field had a negative effect on crop productivity. This result provides evidence that soil quality can be diminished when erosion depletes productive top soil. High temperatures were also associated with decreased productivity. A 1-percent increase in temperature led to a 1.5 percent decrease in crop yields.

Table 7.4—Elasticity estimates for soybean producers in Albemarle-Pamlico Drainage, Southern Georgia Coastal Plain, Illinois/Iowa River Basins, Mississippi Embayment, and Central Nebraska River Basins—Tillage adoption

	Adoption model			Chemical input use and crop productivity models	
Variables	No-till	Conservation tillage	Conventional tillage	Herbicide use	Crop yields
				- - - - lbs/acre - - - -	
CONSTANT	-11.93	-18.94**	16.32**	-0.7181	2.074**
COLLEGE	0.0014	-0.0309	0.0205	0.0375**	0.0068
EXPERIENCE	-0.4091**	0.0157	0.1098*	0.0042	-0.0269*
WORKOFF	0.0191	-0.0021	-0.0042	-0.0134	-0.0094**
TENURE	-0.0084	-0.0381	0.0282	-0.0059	0.0009
ACRES	0.2624**	0.0039	-0.0799**	0.0163	0.0329**
ROTATION	-0.3022**	0.1515**	-0.0135	0.0469	0.0490**
DBL_CROP	—	—	—	—	-0.0067**
MANURE	0.0565**	0.0112	-0.0242**	—	—
IRRIGATION	-0.0946	0.0538**	-0.0085**	—	0.0241**
ADVICE/INFO	—	—	—	0.0264	—
COMPLY	-0.0477**	0.0744	-0.0363**	—	—
CVPLAN	0.0330**	-0.0936	0.0536**	—	—
PROGRAM	—	—	—	0.0301	-0.0158
INSURE	0.1088	0.1280	-0.1186	-0.0164	-0.0113**
WATERBODY	-0.1506	0.0075	0.0392	0.0330	0.0032
SLP	0.0812	0.0038	-0.0265	0.0342	-0.0217
PISOIL	0.2877	0.0012	-0.0855	0.2608*	0.2163**
EROTON	-0.0117**	-0.0172	0.0082	-0.0294**	-0.0269**
RAIN	6.5083**	-2.0019	-0.5624	1.1257**	0.0729
TEMP	0.4273	5.3777**	-3.7616**	—	-1.475**
PROB(CONSERVATION)	—	—	—	-0.0343	0.0185
PROB(CONVENTIONAL)	—	—	—	-0.0409	-0.0362

* Significant at the 10-percent level. ** Significant at the 5-percent level.

Note: Elasticities represent a percent change in the dependent variable given a 1-percent change in the mean of the explanatory variable.

Corn in the Illinois/Iowa, Central Nebraska, and White River Basins

Table 7.5 presents the sample means and the number of observations for corn producers in the Illinois/Iowa, Central Nebraska and White River Basins. The change in percent predicted adoption is presented in table 7.6, and elasticity estimates for the adoption model are displayed in table 7.8. The category of soil management practices assessed in this section include those designed primarily to prevent soil from entering waterways once sediment has left a field. This category and the motivation behind its choice are described in chapter 5.[3]

The results of the adoption model show no significant effects associated with any of the human capital variables. The probability of adoption was significantly less for producers who operated larger farms, however. This result differs from results shown in table 5.4, which included all crops and areas. Producers who practiced crop rotations were more likely to use water quality protection practices, whereas irrigators were less likely to use water quality practices.

[3] Water quality protection practices include grassed waterways, filter strips, grade stabilization structures, and critical area planting.

Table 7.5 - Sample means from water quality practices adoption models for corn producers in Illinois/Iowa, Central Nebraska, and White River Basins regions

Variables	Means
WATER QUALITY PRACTICE	.37
COLLEGE	.40
EXPERIENCE	24
WORKOFF	40
TENURE	.39
ACRES	995
ROTATION	.68
MANURE	.18
IRRIGATION	.18
COMPLY	.15
CVPLAN	.53
INSURE	.59
WATERBODY	.34
SLP	103
PISOIL	.92
EROTON	31
RAIN	2.8
TEMP	50
Number of observations	1518

Conservation policies significantly increased the probability of adoption of water quality practices. The elasticity estimates from table 7.8 show that the probability of adoption increased about 0.06 for producers who were subject to conservation compliance compared to those who were not subject. Producers who received technical assistance show a greater increase in the adoption probability, about 0.26, compared to those who did not seek assistance in developing a conservation plan.

The location of the field, soil quality, and weather conditions were significant determinants in corn producers' decisions to adopt water quality practices.

Table 7.6—Change in percent predicted adoption of soil conservation practices to protect water quality for corn producers in Illinois/Iowa, Central Nebraska, and White River Basins Regions

Variables	Water quality practices
CONSTANT	0.7344**
COLLEGE	0.0422
EXPERIENCE	-0.0497*
WORKOFF	0.0040
TENURE	0.0318
ACRES	-0.0348**
ROTATION	0.1012**
MANURE	0.0264
IRRIGATION	-0.1283**
COMPLY	0.1401**
CVPLAN	0.1786**
INSURE	0.0047
WATERBODY	0.0743**
SLP	0.0658
PISOIL	0.3985**
EROTON	0.0175
RAIN	1.3290**
TEMP	-3.0427**
Percent predicted adoption	34.4
Percent correct predictions	69.8
Pseudo R^2 [1]	0.23

* Significant at the 10-percent level.
** Significant at the 5-percent level.
[1] Veall and Zimmerman's pseudo R^2.

Note: For the table, the coefficients estimated from the limited dependent model have been converted into change in percent predicted adoption. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, RKLS, WIND, RAIN, and TEMP), the reported value is the change in the percent predicted adoption given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in the percent predicted adoption with a unit change of 0.01 from the variable mean. See Appendixes 2-A and 2-B for further details.

Producers who had fields near a lake or a stream (WATERBODY) were more likely to use water quality practices. Additionally, water quality practices were more often adopted on fields with higher soil quality. These results indicate that producers with high-quality soil and fields near a water body may be applying intensive measures both to maintain soil quality and to protect water quality.

Table 7.7 displays the estimates of input demand and crop-yield effects for corn producers. The elasticity estimates are shown in table 7.8. The factors that determined herbicide applications differed from the factors that affected insecticide use. Insecticide applications by farmers who used more intensive soil conservation efforts was 0.44 pounds of active ingredients per acre higher than those who did not use these practices. Herbicide applications, however, were not affected by use of water-quality protection practices.

Results from the herbicide-use model indicate that increased amounts of herbicides were applied by producers who operated a greater number of acres, received pest management advice, had crop insurance, or were located in areas with higher rainfall levels. Producers with more experience used lower quantities of herbicides.

Although producers used less insecticide if they used crop rotations for pest management than did producers who grew corn continuously, the total effect of crop rotations on insecticide use depends on the influence of this variable on adoption decisions as well.[4] The

[4] Determining the total effect of a variable on input demand or crop yield, given its effect on technology adoption decisions, makes sense only if the variables used to calculate total effects are significant.

Table 7.7—Estimates of input demand and crop yield effects for corn producers in the Central Nebraska, Illinois/Iowa and White River Basins Regions — Adoption of soil conservation practices to protect water quality

Variables	Herbicide use	Insecticide use	Nitrogen use	Crop yields
		lbs/acre		
CONSTANT	2.1521*	-0.8010**	-173.28**	-1324.2
COLLEGE	0.0126	0.0032	3.5823	328.05**
EXPERIENCE	-0.0063**	0.0006	0.0402	-2.6869
WORKOFF	-0.0006	-0.0002	0.0062	-1.8951**
TENURE	0.0256	0.0022	-10.383**	67.262
ACRES	0.1632**	0.0858	0.0034**	144.40**
ROTATION	-0.0050	-0.2482**	-6.6337*	380.93**
IRRIGATION	0.2166	0.1335**	43.763**	2991.7**
ADVICE	0.1580**	0.0192	0.1833	—
PROGRAM	0.1154	-0.0364	7.3854*	150.43
INSURE	0.3033**	0.0237	-0.3360	232.32**
WATERBODY	-0.0424	-0.0395*	-8.4738**	-85.228
SLP	-0.0011	0.0008*	0.0969	-4.6321**
PISOIL	-0.0091	0.2213**	27.450**	1469.2**
EROTON	-0.0015	-0.0002	-0.1706**	-3.7653**
RAIN	0.8027**	-0.1334	7.4449	-1451.8**
TEMP	-0.0567	0.0122	5.0659**	194.38**
PROB(WATER)	0.3310	0.4401**	0.5396	-625.45
Mean of dependent variable	2.72	0.23	127.58	7799.2
Adjusted R^2	0.216	0.089[1]	0.151	0.449

* Significant at the 10-percent level.
** Significant at the 5-percent level.

[1] Adjusted R^2 for insecticide use model is from the OLS estimation.
Note: The coefficients estimated from both the insecticide use and yield equations have been converted to the change in insecticide use or yields. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, and TEMP), the reported value is the change in insecticide use or yields given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in insecticide use or yields with a unit change of 0.01 from the variable mean. See Appendixes 7-A and 7-B for further details.

elasticities in table 7.8 show that the *direct* effect of a 1-percent increase in the use of crop rotations is to decrease insecticide use by 0.7185 percent. Also, it is shown that the effect of a 1-percent increase in rotation increases the adoption of water-quality practices by 0.1865 percent, while a 1-percent increase in the adoption of these practices increased insecticide use by 0.6916 percent. Hence, the *indirect* effect of crop rotations on insecticide applications would be (0.1865)*(0.6916), or 0.1290 percent. Therefore, the total factor effect of a 1-percent increase in the use of crop rotations on insecticide use would be (0.1290) + (-0.7185), or -0.5895 percent. In this case, incorporating the indirect effect of crop rotations on insecticide use reduced the magnitude of the effect.

Nitrogen applications by corn producers in the sample averaged about 128 pounds per acre. While many factors had a significant influence on nitrogen use, the adoption of water-quality protection practices did not significantly affect the amount of nitrogen applied. Nitrogen use was significantly greater for producers who operated more acres. Cropping practices were also significant factors in determining nitrogen applications. Irrigation use was positively correlated with nitrogen use.

Nitrogen applications were also dependent on the location of the field, soil quality, and weather conditions. Fields adjacent to a water body received significantly less nitrogen, about 8.5 pounds per acre less (table 7.7), than fields that were not near a lake or stream. This result is encouraging, since it is important to protect water quality by reducing nutrient contamination of waterways. Producers using soil conservation practices to protect water quality may reside in regions where water quality improvement is a priority, or they may be more attentive to water quality problems in general. While higher soil productivity levels increased the amount of nitrogen used, higher soil erosion levels decreased nitrogen applications.

Table 7.8—Elasticity estimates for corn producers in the Central Nebraska, Illinois/Iowa, and White River Basins Regions — Adoption of soil conservation practices to protect water quality

	Adoption model	Chemical input use and crop productivity models			
Variables	Water quality practices	Herbicide use	Insecticide use	Nitrogen use	Crop yields
		lbs/acre			
CONSTANT	1.992**	0.7906*	-3.415**	-1.358**	-0.1698
COLLEGE	0.0453	0.0018	0.0054	0.0112	0.0166**
EXPERIENCE	-0.1348*	-0.0567**	0.0614	0.0077	-0.0084
WORKOFF	0.0109	-0.0084	-0.0271	0.0019	-0.0096**
TENURE	0.0335	0.0037	0.0037	-0.0316**	0.0034
ACRES	-0.0945**	0.0600**	0.5633	0.0270**	0.0185**
ROTATION	0.1865**	-0.0012	-0.7185**	-0.0355*	0.0332**
MANURE	0.0130	—	—	—	—
IRRIGATION	-0.0610**	0.0140	0.1000**	0.0601**	0.0672**
ADVICE	—	0.0281**	0.0398	0.0004	—
COMPLY	0.0582**	—	—	—	—
CVPLAN	0.2574**	—	—	—	—
PROGRAM	—	0.0354	-0.1293	0.0483*	0.0161
INSURE	0.0076	0.0662**	0.0599	-0.0016	0.0178**
WATERBODY	0.0684**	-0.0053	-0.0571*	-0.0226**	-0.0037
SLP	0.1783	-0.0423	0.3726*	0.0780	-0.0611**
PISOIL	1.081**	-0.0031	0.8687**	0.1985**	0.1734**
EROTON	0.0474	-0.0178	-0.0266	-0.0419**	-0.0152**
RAIN	3.606**	0.8233**	-1.588	0.1629	-0.5198**
TEMP	-8.255**	-1.036	2.581	1.974**	1.239**
PROB(WATER)	—	0.0448	0.6916**	0.0016	-0.0296

* Significant at the 10-percent level.
** Significant at the 5-percent level.

Note: Elasticities represent a percent change in the dependent variable given a 1-percent change in the mean of the explanatory variable.

As we expected, the use of water-quality protection practices did not significantly affect corn yields. However, other factors did have a significant effect. Producers with some college education had higher crop yields than those with no college education. Larger farms were also associated with higher yields. Producers who worked more days off the farm experienced yield declines. Cropping practices also affected crop productivity. Producers who used crop rotations for pest management or used irrigation technology had significantly higher yields. The same was true for producers who obtained crop insurance.

Finally, as expected, crop productivity depended greatly on soil quality and weather conditions. High levels of soil productivity and temperature were correlated with increased corn yields. Conversely, yields were significantly lower for producers who had high soil-leaching potential, erosion levels, or rainfall levels.

Effects of Pest Management Adoption on Chemical Use and Crop Yields

Pest management practices may have a significant effect on chemical use and crop yields. One of our underlying hypotheses is that producers who adopt nonchemical pest management practices have lower costs because of less use of synthetic chemicals such as pesticides. Producers may have an incentive to adopt nonchemical pest management practices if they expect an increase in the quantity or quality of output. Many studies have shown significant increases in yields for farmers who adopt pest management practices such as scouting, or using beneficial insects, or who destroy crop residues (Adkinsson et al., 1981; Frisbie et al.,1976; Masud et al., 1981; and Napit et al., 1988).

The analysis in this section examines two case studies about the effects of nonchemical pest management use decisions on chemical use and crop yields. Most farmers implement pest management strategies to target a specific commodity with specific pests. In addition, chemical requirements are often crop-specific. Therefore, the case studies we present are commodity-specific.

The first case study investigates input demand and crop productivity of cotton producers in the Albemarle-Pamlico Drainage, Mississippi Embayment, Southern Georgia Coastal Plain, and Southern High Plains. We chose cotton to study because it requires intensive use of insecticides compared with other crops. Cotton is often plagued by the bollworm or the boll weevil. Practices such as scouting or biological controls may combat these pests without use of synthetic chemicals. The second case study examines corn producers in Central Nebraska, Illinois/Iowa, and White River Basins. Corn growers in general do not use as much insecticide as cotton growers, but corn rootworm is a primary pest problem for corn farmers. Practices that break up the rootworm's cycle, such as rotations, may be an effective control.

Cotton in the Albemarle-Pamlico Drainage, Mississippi Embayment, Southern Georgia Coastal Plain, and Southern High Plains

Table 7.9 presents the sample means and the number of observations for cotton producers in the Albemarle-Pamlico Drainage, Mississippi Embayment, Southern Georgia Coastal Plain, and Southern High Plains regions. The pest management practices chosen were the use of biological controls, scouting, destroying crop residues, and rotations. Each practice is described more fully in chapter 4. The adoption model results are presented in table 7.10. The results of the adoption models are consistent with those reported in chapter 4.

Table 7.9—Sample means from pest management adoption models for cotton growers in the Albemarle-Pamlico Drainage, Mississippi Embayment, Southern Georgia Coastal Plain, and Southern High Plains

Variables	Means
BIOLOGIC	.23
SCOUTING	.51
DESTROY_RES	.53
ROTATION	.18
COLLEGE	.51
EXPERIENCE	23
WORKOFF	19
TENURE	.28
ACRES	2170
DBL-CROP	.04
IRRIGATION	.37
PROGRAM	.95
INSURE	.50
ADVICE	.47
WATERBODY	.44
SLP	136
PISOIL	.73
EROTON	38
TEMP	60
Number of observations:	747

The results from the input demand equation for insecticide use are presented in table 7.11. Farmers with crop insurance applied significantly lower amounts of insecticides. Farmers with a higher soil-leaching potential apply more pounds of insecticides than do those with less leachable soils. Temperature also has a positive and significant effect on insecticide use. Warmer climates may be more prone to pest infestations, and therefore, farmers in these areas may apply more chemicals to control pest outbreaks.

Biological controls, crop residue destruction, and rotations had no significant effect on insecticide applications. Scouting, however, had a significant and positive effect on insecticide use, which is consistent with findings from other studies (Hatcher et al., 1984; Napit et al., 1988; Ferguson et al., 1993), and may indicate that monitoring pest populations per se is not a chemical-reducing activity.

The results from the yield equation for cotton growers are presented in table 7.11. Farmers who worked more days off the farm had significantly lower yields than farmers who spent more time working on the farm. On the other hand, farmers who owned the land, as

Table 7.10—Change in the percent predicted adoption of pest management practices for cotton growers in the Albemarle-Pamlico Drainage, Mississippi Embayment, Southern Georgia Coastal Plain, and Southern High Plains — Pest management practice adoption

Variables	Biological controls	Scouting	Destroying crop residues	Rotations
CONSTANT	-7.2499**	-1.5085	-7.4372**	1.4668
COLLEGE	0.0333	0.0991**	-0.0296	0.0154
EXPERIENCE	-0.0199	-0.0593	-0.0652	0.0119
WORKOFF	0.0012	-0.0020	0.0150**	0.0028
TENURE	-0.0208	-0.1184**	0.0087	0.0208
ACRES	0.0359**	0.1316**	-0.0500**	0.0263
DBL-CROP	-0.0784	0.1545	-0.3338**	0.0031
IRRIGATION	0.0151	0.1643**	-0.0656	0.1194**
PROGRAM	0.0006	0.0226	-0.0894	0.0393
INSURE	-0.0048	0.0854	0.0789	0.1052**
ADVICE	0.0774**	0.2563**	0.1701**	0.0693**
SLP	-0.0327	-0.5941**	0.1634	-0.0501
PISOIL	-0.0692	-0.0424	0.1034	-0.0070
EROTON	—	—	0.0133	—
TEMP	1.636**	0.1716	1.8289**	-0.5034
% predicted adoption	15.4	51.8	54.4	12.1
% correct predictions	79.9	73.0	69.1	87.8
Pseudo R^2 [1]	.39	.45	.24	.47

— Variable not included in the adoption model.
** Significant at the 5-percent level.
[1] Veall and Zimmerman's pseudo R^2.

Note: For the table, the coefficients estimated from the limited dependent model have been converted into change in percent predicted adoption. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, AND TEMP), the reported value is the change in the percent predicted adoption given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in the percent predicted adoption with a unit change of 0.01 from the variable mean. See Appendixes 2-A and 2-B for further details.

Table 7.11—Estimates for insecticide use and crop yield effects for cotton in the Albemarle-Pamlico Drainage, Mississippi Embayment, Southern Georgia Coastal Plain, and Southern High Plains Regions — Pest management practice adoption

Variables	Insecticide use	Cotton yields
	lbs/acre	
CONSTANT	-40.9648**	538.674**
COLLEGE	-0.1778	-8.1721
EXPERIENCE	0.0447	0.0711
WORKOFF	0.0106	-8.2541**
TENURE	0.2011	78.2296**
ACRES	-0.2368*	5.2589
IRRIGATION	-0.3249	210.622**
INSURE	-0.6487**	-16.4720
ADVICE	-0.4849	67.6538**
WATERBODY	0.0102	—
SLP	2.1579**	-140.910**
PISOIL	0.4292	-58.2138
EROTON	0.0601	—
TEMP	9.4594**	—
PROB(BIOLOGIC)	0.2275	Insignificant[1]
PROB(SCOUTING)	1.9259**	Insignificant[1]
PROB(DESTROY_RES)	0.1891	Insignificant[1]
PROB(ROTATION)	0.2421	Insignificant[1]
Mean of dependent	1.1317	560

** Significant at the 5-percent level.
* Significant at the 10-percent level.

[1] The data were not sufficient to estimate a yield equation model combining the practices together, so the model was run separately for each practice. No coefficients on the practice variables were statistically significant.

Note: The coefficients estimated from both the insecticide use and yield equations have been converted to the change in insecticide use or yields. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, and TEMP), the reported value is the change in insecticide use or yields given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in insecticide use or yields with a unit change of 0.01 from the variable mean. See Appendixes 7-A and 7-B for further details.

well as those who irrigated, were significantly more likely to have higher yields than renters or those who did not irrigate. The only natural resource variable that significantly affected yields was soil-leaching potential. The effect was negative, indicating that more leachable soils produced lower yields.

The results indicate that no chosen pest management practices had a significant effect on yields for cotton growers in the sample. The model elasticities (calculated at the means of the variables) are presented in table 7.12. Because elasticities are not scale-dependent, they provide a convenient way to compare the effects described in the model.

Corn in the Central Nebraska, Illinois/Iowa, and White River Basins

Table 7.13 presents the sample means and the number of observations for corn producers in the Central Nebraska, Iowa/Illinois, and White River Basins. Biological controls are not included in the analysis for corn because fewer than 3 percent of the corn farmers in these regions had adopted this practice. The results from the adoption models are presented in table 7.14.

The results from the input demand equation for insecticide use are presented in table 7.15. Farm ownership was positively and significantly associated with insecticide use, and farmers who irrigate apply more insecticides than those who do not irrigate. The natural resource variables of soil-leaching potential and soil productivity were also positively and significantly associated with insecticide use. Warmer temperature on the other hand, had a negative effect on insecticide use. This result may reflect some geographical differences of the regions that were not captured in the dummy variables.

Of the three pest management practices analyzed, only the destruction of crop residues had a significant effect on insecticide use. The coefficient on destroying crop residues is negative, indicating that farmers who have adopted this practice apply less insecticides than those who have not adopted the practice. This result is consistent with our a priori expectations that destroying crop residues may be an effective way to reduce chemical use.

The results from the yield equation also are presented in table 7.15. More highly educated farmers had higher yields, whereas those who worked more days off the farm had significantly lower yields. The size of the

Table 7.12—Elasticity estimates for cotton producers in the Albemarle-Pamlico Drainage, Mississippi Embayment, Southern Georgia Coastal Plain, and Southern High Plain Regions — Pest management practices adoption

Variables	Adoption models				Insecticide use and cotton yield models	
	Biological controls	Scouting	Crop residue destruction	Rotations	Insecticide use	Yield
					- - - lbs/acre - - -	
COLLEGE	0.0737	0.0981**	-0.0284	0.0441	-0.0795	-0.0074
EXPERIENCE	-0.0871	-0.1159	-0.1233	0.0671	0.0395	0.0001
WORKOFF	0.0055	-0.0039	0.0284**	0.0159	0.0094	-0.0147**
TENURE	-0.0253	-0.0646**	0.0046	0.0327	0.0496	0.0385**
ACRES	0.1570**	0.2574**	-0.0946**	0.1484	-0.2092	0.0094
DBL-CROP	-0.0121	0.0106	-0.0222**	0.0006	—	—
IRRIGATION	0.0246	0.1196**	-0.0462	0.2504**	-0.1068	0.1401**
PROGRAM	0.0025	0.0417	-0.1599	0.2095	—	—
INSURE	-0.0103	0.0831	0.0742	0.2949**	-0.2851**	-0.0146
ADVICE	0.1605**	0.2379**	0.1527**	0.1852**	-0.2033	0.0572**
SLP	-0.1429	-1.1620**	0.3092	-0.2822	1.9068**	-0.2517**
PISOIL	-0.3023	-0.0829	0.1956	-0.0395	0.3793	-0.1040
TEMP	7.1503**	0.3356	3.4605**	-2.8378	8.3587**	—
EROTON			0.0252		0.0531	—
WATERBODY					0.0040	—
PROB(BIOLOGIC)					0.2010	-0.0077
PROB(SCOUTING)					1.7018**	-0.2116
PROB(DESTROY_RES)					0.1671	0.1056
PROB(ROTATION)					0.2140	0.0917

— Variable not included in model.
** Significant at the 5-percent level.

farm was positively associated with increased yields, and the use of irrigation was also significantly and positively associated with yields. Farmers with crop insurance had increased yields compared to those without insurance.

All natural resource variables appear to be significantly associated with yields. The soil-leaching potential is negative, whereas soil productivity is positively associated with yields. The inherent potential of the soil to erode has a negative relationship to yield. High temperature is positively associated with yields. Of the chosen pest management practices, we observe that only scouting had a significant effect on yield, and that effect was positive.

The effects from the adoption models and insecticide demand and crop yield equations are reported as elasticities (calculated at the means of the variables) in table 7.16. We can observe, for instance, that the direct effect of a 1-percent increase in the use of irrigation on yields is 0.07 percent. The effect of irrigation use on the adoption of scouting is about 0.14 percent, and 1-percent increase in scouting increases yields by 0.04 percent, giving a joint effect on yield from the irrigation/scouting factors of 0.001 percent. When the other practices are included, the total of all the effects of irrigation on yields is 0.098 percent.

Table 7.13—Sample means from pest management adoption models for corn growers in the Iowa/Illinois, Central Nebraska, and White River Basins

Variables	Means
SCOUTING	.09
DESTROY_RES	.09
ROTATION	.68
COLLEGE	.39
EXPERIENCE	24
WORKOFF	40
TENURE	.39
ACRES	991
DBL-CROP	.01
IRRIGATION	.17
PROGRAM	.83
INSURE	.59
ADVICE	.48
WATERBODY	.34
SLP	103
PISOIL	.92
EROTON	31
TEMP	50
Number of observations	1549

Effects of Nutrient Management on Nitrogen Use and Crop Yields

Using nutrient management practices may have a significant effect on nitrogen fertilizer use and crop yields. We would expect that farmers who adopt nutrient management practices will either maintain or increase their yields or reduce input costs. The analysis presented in this section examines the effect of nutrient management decisions on nitrogen use and crop yields.

Nutrient management strategies can be applied to any crop. However, crops vary in nitrogen fertilizer requirements. We chose corn to model the adoption of nutrient management techniques and assess the effects of adoption on nitrogen use and crop yields because it is a nitrogen-intensive crop. Corn accounts for over 40

Table 7.14--Change in the percent predicted adoption of pest management practices for corn growers in the Iowa/Illinois, Central Nebraska, and White River Basins

Variables	Scouting	Destroying crop residues	Rotations
CONSTANT	0.0240	-0.4033	-2.1704*
COLLEGE	0.0345**	-0.0262**	0.0237
EXPERIENCE	0.0016	-0.0129	0.0007
WORKOFF	-0.0008	0.0050*	-0.0056
TENURE	0.0028	0.0039	-0.0499*
ACRES	0.0205**	-0.0147*	0.0168
IRRIGATION	0.0734**	-0.0036	-0.3275**
PROGRAM	0.0457**	-0.0406**	-0.0530
INSURE	0.0137	0.0045	-0.0193
ADVICE	0.0283**	0.0068	0.0340
SLP	0.0344*	0.0093	-0.3077**
PISOIL	-0.0065	0.0472	-0.0682
EROTON	—	-0.0350**	—
TEMP	-0.1026	0.0903	0.6772**
% predicted adoption:	5.3	7.1	69.7
% correct predictions:	89.9	88.4	77.3
Pseudo R^2 [1]	.30	.13	.32

— Variable not included in the adoption model.
** Significant at the 5-percent level.
* Significant at the 10% level.
[1] Veall and Zimmerman's pseudo R^2.
Note: For the table, the coefficients estimated from the limited dependent model have been converted into change in percent predicted adoption. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, AND TEMP), the reported value is the change in the percent predicted adoption given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in the percent predicted adoption with a unit change of 0.01 from the variable mean. See Appendixes 2-A and 2-B for further details.

percent of nitrogen fertilizer use in the United States (Taylor, 1997).

Corn in the Illinois/Iowa, Central Nebraska, and White River Basins

Table 7.17 presents the sample means and the number of observations for corn producers in Illinois/Iowa, Central Nebraska, and White River Basins. Two separate nutrient management technologies were studied. The first—modern nutrient management practices—includes N-testing, split nitrogen applications, and micronutrient use.[5] The second technology (the use of legumes in rotation) represents a traditional approach to nutrient management. Of the 1,520 observations, 38 percent of the sample use modern practices and non-adopters were 62 percent, while 53 percent grew legumes in rotation with corn.

Table 7.15—Estimates for insecticide use and crop yield effects for corn in the Iowa/Illinois, Central Nebraska, and White River Basins Regions—Pest management practice adoption

Variables	Insecticide	Corn yield
	lbs/acre	
CONSTANT	2.1997*	-13301**
COLLEGE	-0.0385	377.41**
EXPERIENCE	-0.0179	-24.570
WORKOFF	0.0101	-96.991**
TENURE	0.0770**	38.429
ACRES	-0.0296	225.01**
IRRIGATION	0.5246**	3188.3**
INSURE	0.0499*	229.55**
ADVICE	0.0006	-47.875
SLP	0.4558**	-600.91**
PISOIL	0.4430**	1005.4**
EROTON	-0.0053	-111.53**
TEMP	-0.9679**	4166.6**
PROB(SCOUTING)	0.0035	3410.7**
PROB(DESTROY_RES)	-0.1013**	Insignificant[1]
PROB(ROTATION)	0.7286*	Insignificant[1]
Mean of dependent	0.2358	7761

** Significant at the 5-percent level.
* Significant at the 10-percent level.

[1] The data were not sufficient to estimate a yield equation model combining all of the practices together, so the model was run separately for each practice. The only practice with a statistically significant coefficient was scouting.Note: The coefficients estimated from both the insecticide use and yield equations have been converted to the change in insecticide use or yields respectively. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, and TEMP), the reported value is the change in insecticide use or yields given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in insecticide use or yields with a unit change of 0.01 from the variable mean. See Appendixes 2-A and 2-B for further details.

Table 7.17 presents the sample means and the number of observations for corn producers in Illinois/Iowa, Central Nebraska, and White River Basins. Two separate nutrient management technologies were studied. The first—modern nutrient management practices—includes N-testing, split nitrogen applications, and micronutrient use.[5] The second technology (the use of legumes in rotation) represents a traditional approach to nutrient management. Of the 1,520 observations, 38 percent of the sample use modern practices and non-adopters were 62 percent, while 53 percent grew legumes in rotation with corn.

The changes in percent predicted adoption are shown in table 7.18. In the modern practices model, human capital was not a significant predictor of use, except that farmers with a college education were more likely to adopt modern practices. The use of irrigation had a positive and significant effect on the adoption of modern practices. Also, receiving outside information on fertilizer use had a significant and positive influence on the adoption of modern practices.

Producers who have farmed the longest are more likely to use legumes in rotation. Farmers who own the field and who use irrigation were less likely to plant legumes in rotation. Soil-leaching potential had a significant negative effect on the adoption of legumes in rotation among corn farmers.

Effects of modern practices on nitrogen use and yields Nitrogen fertilizer use by corn producers in the combined areas averaged 127 pounds per acre, and average crop yield for the three regions was 7,789 pounds per acre. The estimates of nitrogen demand and crop yield effects for corn producers are presented in table 7.19. The R^2 for the nitrogen use model was 0.11 and was 0.15 for yield.

The factors that had a significant impact on nitrogen use were: tenure, acres operated, the use of irrigation, erosion levels, and the amount of rainfall. More highly educated producers have increased corn yields. In addition, farmers who operated large farms (5,000 acres or more), or had crop insurance, or irrigated had higher yields. On the other hand, farmers who worked more days off farm had lower crop yields of about 2.4 pounds per acre per day worked off farm. As expected, productive soils were associated with increases in corn yields, and erodible soils were associated with decreases in yields. In addition, warmer temperatures significantly enhanced crop yields.

The results of the model showed that the use of modern practices (MODPRAC) had no significant effect on nitrogen fertilizer use and no significant effect on corn yields. The model elasticities are presented in table 7.20.

Effects of legumes in rotation on nitrogen use and yields The estimates of nitrogen demand and crop

[5] More detail on the category of "modern practices" is given in chapter 3.

yield effects for the legumes in rotation model are presented in table 7.21. Increased nitrogen use was associated with larger farms and with farmers who irrigated their corn fields. Farmers with productive soils applied about 27 pounds more nitrogen per acre than farmers with less productive soils. In addition, warmer temperatures had a positive effect on nitrogen use. Conversely, erosive soils were associated with a significant but slightly lower use of nitrogen fertilizer.

Farmers with more education had significantly higher corn yields, whereas those who worked more days off the farm had significantly lower yields. Also, corn farmers who owned the field had higher crop yields than renters. The size of the farm was positively associated with increased yields. The use of irrigation also significantly increased yields. Soil productivity, as expected, was positively associated with yields, and the potential of soil to erode was negatively associated with yields. Crop productivity was increased by warm, dry weather.

The results of the model showed that using legumes in rotation had no significant effect on nitrogen fertilizer use, but using legumes in rotation significantly increased corn yields. The elasticity estimates for the

Table 7.17—Sample means from nutrient management adoption models for corn producers in the Illinois/Iowa, Central Nebraska, and White River Basins

Variables	Means
MODERN PRACTICES	.38
LEGUMES IN ROTATION	.53
COLLEGE	.40
EXPERIENCE	24
WORKOFF	39
TENURE	.38
ACRES	998
IRRIGATION	.17
PROGRAM	.83
ADVICE	.28
INSURE	.60
SLP	103
PISOIL	.92
EROTON	31
RAIN	2.8
TEMP	50
Number of observations:	1520

Table 7.16—Elasticity estimates for corn producers in the Iowa/Illinois, Central Nebraska, and White River Basins — Pest management practice adoption

	Adoption models			Insecticide use and corn yield models	
Variables	Scouting	Crop residue destruction	Rotations	Insecticide use	Crop yield
				- - - lbs/acre - - -	
COLLEGE	0.1461**	-0.1132**	0.0139	-0.0645	0.0191**
EXPERIENCE	0.0173	-0.1407	0.0010	-0.0761	-0.0032
WORKOFF	-0.0091	0.0545	-0.0083	0.0428	-0.0125**
TENURE	0.0114	0.0166	-0.0285	0.1258**	0.0019
ACRES	0.2202**	-0.1605	0.0249	-0.1256	0.0290**
IRRIGATION	0.1367**	-0.0069	-0.0842**	0.3867**	0.0713**
PROGRAM	0.4078**	-0.3696**	-0.0653	—	—
INSURE	0.0867	0.0288	-0.0169	0.1252	0.0176**
ADVICE	0.1463**	0.0362	0.0243	0.0011	-0.0030
SLP	0.3686	0.1014	-0.4553**	1.9332**	-0.0774**
PISOIL	-0.0697	0.5164	-0.1009	1.8788**	0.1295**
TEMP	-1.0998	0.9880	1.0021**	-4.1048**	0.5369**
EROTON		-0.3827**		-0.0224	-0.0144**
PROB(SCOUTING)				0.0147	0.0413**
PROB(DESTROY_RES)				-0.4295**	0.0177
PROB(ROTATION)				3.0902	-0.2506

— Variable not included in model.
** Significant at the 5-percent level.

nitrogen fertilizer demand and corn yield models are presented in table 7.22.

Effects of Irrigation on Chemical Use and Crop Yields

The analysis in this section examines the effect of irrigation decisions on chemical use and crop yields. Two case studies are presented. The first investigates input demand and crop productivity for corn producers in the Central Nebraska River Basins. The second case study examines differences between cotton producers who irrigate and those who do not irrigate in the Albemarle-Pamlico Drainage, Mississippi Embayment, Southern Georgia Coastal Plain, and Southern High Plains.

Table 7.18—Change in percent predicted adoption of nutrient management practices for corn producers in the Illinois/Iowa, Central Nebraska, and White River Basins

Variables	Modern practices	Legumes in rotation
CONSTANT	0.4248	-0.4693
COLLEGE	0.0624**	-0.0459
EXPERIENCE	-0.0485*	0.2325**
WORKOFF	-0.0061	-0.0164
TENURE	0.0283	-0.6260**
ACRES	0.0289	-0.0094
IRRIGATION	0.3185**	-1.9116**
PROGRAM	0.0037	0.1971
ADVICE	0.0865**	0.2249*
INSURE	0.0512*	-0.0360
SLP	0.0558	-1.0862**
PISOIL	-0.0898	0.4243
EROTON	0.0006	-0.0067
RAIN	0.2367	-1.2451
TEMP	-0.8075	2.2930
% predicted adoption	38.0	51.0
% correct predictions	74	68
Pseudo R^2 [1]	.29	.28

** Significant at the 5-percent level.
* Significant at the 10-percent level.
[1] Veall and Zimmerman's pseudo R^2.

Note: For the table, the coefficients estimated from the limited dependent model have been converted into elasticities or percent change in predicted adoption. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, RAIN AND TEMP), the reported value is the change in the percent predicted adoption given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in the percent predicted adoption between the values of 0 and 1. See Appendixes 2-A and 2-B for further details.

Both cases include changes in insecticide and nitrogen use.[6]

Corn in the Central Nebraska River Basins

Table 7.23 presents the sample means and the number of observations for corn producers in the Central Nebraska River Basins. These producers were separated into three categories used in the adoption analyses

[6] A tobit model was used to estimate the insecticide-use model, because many producers did not use insecticides. The tobit model provides unbiased estimates that reflect the truncated distribution of the data.

Table 7.19—Estimates of nitrogen use and crop yield effects for corn in the Illinois/Iowa, Central Nebraska, and White River Basins—Modern nutrient management practices adoption

Variables	Nitrogen use	Corn yield
	lbs/acre	
CONSTANT	-96.8037**	963.4624
COLLEGE	2.7885	455.2075**
EXPERIENCE	0.0859	-6.6705
WORKOFF	0.0221	-2.3699**
TENURE	-9.2128**	73.1260
ACRES	5.5589**	219.6795**
IRRIGATION	47.2214**	3909.282**
PROGRAM	4.2325	116.8808
ADVICE	-1.3067	—
INSURE	—	284.5593**
SLP	—	-4.2693*
PISOIL	19.5692	955.6261**
EROTON	-0.1382**	-4.7247**
RAIN	51.5423**	—
TEMP	—	70.3895**
PROB(MODPRAC)	19.7487	-2687.786
Mean of dependent	127	7789
Adjusted R^2	.11	.15

** Significant at the 5-percent level.
* Significant at the 10-percent level.

Note: The coefficients estimated from both the insecticide use and yield equations have been converted to the change in insecticide use or yields. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, and TEMP), the reported value is the change in insecticide use or yields given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in insecticide use or yields with a unit change of 0.01 from the variable mean. See Appendixes 7-A and 7-B for further details.

described in chapter 6: 1) nonirrigators; 2) producers who used a sprinkler system; and 3) producers who used a gravity system. Of the 61 percent of producers who irrigated, half used a sprinkler system and the other half used a gravity system. The changes in percent predicted adoption are shown in table 7.24. The R^2 for the model is 0.66 and the percent correct predictions is 69 percent.

Farmers with a college education were more likely to irrigate and more likely to use a sprinkler system. Larger, owned operations had a higher probability of using irrigation. Farmers who practiced crop rotations for pest management were more likely not to irrigate and less likely to use a sprinkler system. Producers who had crop insurance had a lower probability of using irrigation. The largest, most significant determinants of irrigation use were natural resource and weather factors. The results closely reflected what was expected, given the attributes of each irrigation system. Producers were more likely not to irrigate on land with steep slopes and low soil leaching potential. Producers had a higher probability of using sprinkler systems if the field had low soil quality, as measured by the soil productivity index, or had a steep slope. In general, producers in areas with high rainfall and low temperatures were less likely to irrigate.

The estimates of pesticide and nitrogen demand and crop yield effects for corn are presented in table 7.25. Corn producers in the Central Nebraska River Basins use about 1.5 and 0.2 pounds active ingredients of herbicides and pesticides per acre.

Using either a sprinkler or gravity irrigation system did not influence the amount of herbicide applied. However, the higher the probability of using a gravity system, the greater the pounds of insecticides applied, as compared to nonirrigators. Producers who participated in a commodity program used about 0.39 pounds of ai per acre more than those who did not participate.

Table 7.20—Elasticity estimates for corn producers in the Illinois/Iowa, Central Nebraska, and White River Basins — Modern nutrient management practices adoption

	Adoption model	Nitrogen input use and corn yield models	
Variables	Modern practices	Nitrogen use	Corn yield
		- - - lbs/acre - - -	
COLLEGE	0.0644**	0.0087	0.0231**
EXPERIENCE	-0.1263*	0.0165	-0.0209
WORKOFF	-0.0159	0.0068	-0.0120**
TENURE	0.0285	-0.0279**	0.0036
ACRES	0.0753	0.0437**	0.0282**
IRRIGATION	0.1442**	0.0645**	0.0872**
PROGRAM	0.0079	0.0277	0.0125
ADVICE	0.0623**	-0.0028	—
INSURE	0.0794*	—	0.0218**
SLP	0.1452	—	-0.0564*
PISOIL	-0.2337	0.1417	0.1131**
EROTON	0.0015	-0.0335**	-0.0188**
RAIN	0.6163	1.1317**	—
TEMP	-2.1017	—	0.4494**
PROB(MODPRAC)	—	0.0596	-0.1326

** Significant at the 5-percent level.
* Significant at the 10-percent level.

Note: Elasticities represent a percent change in the dependent variable given a 1-percent change in the mean of the explanatory variable.

Table 7.21—Estimates of nitrogen use and crop yield effects for corn in the Illinois/Iowa, Central Nebraska, and White River Basins — Legumes in rotation adoption

Variables	Nitrogen use	Corn yield
	lbs/acre	
CONSTANT	-262.8784**	-5568.090**
COLLEGE	3.9438	312.4849**
EXPERIENCE	-0.0403	-8.1188*
WORKOFF	0.0175	-1.8319**
TENURE	-5.2072	378.2197**
ACRES	4.7136**	147.3754**
IRRIGATION	56.3075**	3907.562**
PROGRAM	5.2059	30.4772
ADVICE	-1.3425	—
INSURE	-0.3490	207.3398*
SLP	0.1701*	-0.2447
PISOIL	27.1332**	1104.910**
EROTON	-0.1616**	-4.5907**
RAIN	—	-1533.454**
TEMP	5.1698**	214.4333**
PROB(LEGUME)	29.0180	2619.715**
Mean of dependent	127	7789
Adjusted R^2	.11	.27

** Significant at the 5-percent level.
* Significant at the 10-percent level.

Note: The coefficients estimated from both the insecticide use and yield equations have been converted to the change in insecticide use or yields. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, and TEMP), the reported value is the change in insecticide use or yields given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in insecticide use or yields with a unit change of 0.01 from the variable mean. See Appendixes 7-A and 7-B for further details.

Table 7.22—Elasticity estimates for corn producers in the Illinois/Iowa, Central Nebraska, and White River Basin areas—Legumes in rotation

	Adoption model	Nitrogen input use and corn yield models	
Variables	Legumes in rotation	Nitrogen use	Corn yield
		- - - lbs/acre - - -	
COLLEGE	-0.0087	0.0123	0.0159**
EXPERIENCE	0.1106**	-0.0077	-0.0255*
WORKOFF	-0.0078	0.0054	-0.0093**
TENURE	-0.1150**	-0.0158	0.0188**
ACRES	-0.0045	0.0370**	0.0189**
IRRIGATION	-0.1581**	0.0769**	0.0871**
PROGRAM	0.0780	0.0340	0.0033
ADVICE	0.0296*	-0.0029	—
INSURE	-0.0102	-0.0016	0.0159*
SLP	-0.5164**	0.1374*	-0.0032
PISOIL	0.2018	0.1964**	0.1307**
EROTON	-0.0032	-0.0392**	-0.0183*
RAIN	-0.5922	—	-0.5507**
TEMP	1.0902	2.0189**	1.3692**
PROB(LEGUME)	—	0.1197	0.1767**

** Significant at the 5-percent level.
* Significant at the 10-percent level.

Note: Elasticities represent a percent change in the dependent variable given a 1-percent change in the mean of the explanatory variable.

Table 7.23—Sample means from irrigation adoption models for corn producers in Central Nebraska River Basins

Variables	Means
NONIRRIGATORS	.39
SPRINKLER SYSTEM	.31
GRAVITY SYSTEM	.30
COLLEGE	.40
EXPERIENCE	22
WORKOFF	25
TENURE	.39
ACRES	1148
ROTATION	.38
PROGRAM	.85
INSURE	.58
WATERBODY	.28
SLP	127
PISOIL	.86
SLOPE	3.3
RAIN	2.1
TEMP	49
Number of observations	423

The lack of significant variables in both models, as well as a low model fit, indicates that the variables chosen for the model do not explain fully what factors influence herbicide or insecticide use by corn producers in the Central Nebraska River Basins. Factors, such as target pests and pest intensity, may be more important in determining the amount of pesticides applied. However, the Area Studies survey data did not contain this information.

Nitrogen applications by corn producers in the Central Nebraska River Basins averaged about 108 pounds per acre. The use of irrigation technology, gravity or sprinkler system, was not a significant determinant of nitrogen applications compared to nonirrigators. Producers who used crop rotations applied significantly less nitrogen than those who did not rotate crops, about 18 pounds-per-acre difference. Producers who received fertilizer advice from either a fertilizer company, consultant, or a local extension service applied

Table 7.24—Change in percent predicted adoption of irrigation practices for corn producers in Central Nebraska River Basins

Variables	Nonirrigators	Sprinkler system	Gravity system
CONSTANT	4.4773*	1.4797	-5.9571**
COLLEGE	-0.2209**	0.1608**	0.0600
EXPERIENCE	-0.0210	-0.0023	0.0233
WORKOFF	0.0230*	-0.0008	-0.0001
TENURE	-0.1465**	0.2080**	-0.0615
ACRES	-0.1838**	0.1906**	-0.0067
ROTATION	0.2594**	-0.1564**	-0.1030
PROGRAM	-0.1053	0.0493	0.0560
INSURE	-0.1924**	0.1131	0.0793
WATERBODY	-0.0702	-0.0016	0.0718
SLP	-0.3953**	0.1226	0.2727**
PISOIL	-0.1584	-0.3553**	0.5137**
SLOPE	0.1210**	0.1112**	-0.2321**
RAIN	1.6036**	-0.6680	-0.9356**
TEMP	-5.1470**	-0.9673	6.1141**
% predicted adoption:	42.0	44.6	13.4
% correct predictions:		69	
Pseudo R^2 [1]		0.66	

* Significant at the 10-percent level.
** Significant at the 5-percent level.
[1] Veall and Zimmerman's pseudo R^2

Note: For the table, the coefficients estimated from the limited dependent model have been converted into change in percent predicted adoption. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, SLOPE, RAIN AND TEMP), the reported value is the change in the percent predicted adoption given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in the percent predicted adoption with a unit change of 0.01 from the variable mean. See Appendixes 2-A and 2-B for further details.

Table 7.25—Estimates of input demand and crop yield effects for corn in the Central Nebraska River Basins— Irrigation adoption

Variables	Herbicide use	Insecticide use	Nitrogen use	Crop yield
			lbs/acre	
CONSTANT	1.6445*	-0.6858	-606.80**	-20801**
COLLEGE	-0.0918	0.0022	0.3266	707.48**
EXPERIENCE	-0.0015	-0.0020	-0.0900	5.0742
WORKOFF	-0.0007	-0.0002	0.0062	-2.6840**
TENURE	-0.0894	-0.0507	2.0910	90.943
ACRES	0.0243	-0.00001	0.0009	0.1960*
ROTATION	-0.1933	0.0848	-17.977**	129.27
ADVICE	0.2662*	0.0023	-19.142**	—
PROGRAM	0.3943**	-0.0237	13.116*	-185.79
INSURE	0.0940	0.0676	1.4551	522.91**
WATERBODY	-0.1026	-0.0934**	10.740*	336.65*
SLP	-0.0043	-0.0004	0.1451	-0.1827
PISOIL	-0.1463	0.1766	20.692	1244.0**
EROTON	-0.0014	0.0020**	-0.1063	-2.5424
RAIN	—	-0.0103	-40.917*	-805.27
TEMP	—	0.0065	15.314**	513.57**
PROB(SPRINK)	0.2610	0.2405	21.080	3380.7**
PROB(GRAVITY)	-0.0088	0.3682**	16.8578	3508.1**
Mean of dependent	1.5	0.2	108	6772
Adjusted R^2	0.022	0.071[1]	0.195	0.664

* Significant at the 10-percent level.
** Significant at the 5-percent level.
[1] Adjusted R^2 for insecticide use model is from the OLS estimation.
Note: The coefficients estimated from both the insecticide use and yield equations have been converted to the change in insecticide use or yields. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, and TEMP), the reported value is the change in insecticide use or yields given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in insecticide use or yields with a unit change of 0.01 from the variable mean. See Appendixes 7-A and 7-B for further details.

Table 7.26—Elasticity estimates for corn producers in the Central Nebraska River Basins — Irrigation adoption

	Adoption model			Chemical input use and corn yield models			
Variables	Nonirrigators	Sprinkler system	Gravity system	Herbicide use	Insecticide use	Nitrogen use	Crop yield
					lbs/acre		
CONSTANT	11.48*	4.773	-19.86**	1.112*	-3.345	-5.595**	-3.072**
COLLEGE	-0.2269**	0.2079**	0.0802	-0.0249	0.0044	0.0012	0.0417**
EXPERIENCE	-0.0538	-0.0074	0.0776	-0.0229	-0.2173	-0.0186	0.0166
WORKOFF	0.0589*	-0.0658	-0.0086	-0.0119	-0.0198	0.0013	-0.0102**
TENURE	-0.1460**	0.2608**	-0.0797	0.0235	-0.0961	0.0076	0.0052
ACRES	-0.4714**	0.6147**	-0.0224	0.0164	0.0287	0.0092	0.0332*
ROTATION	0.2547**	-0.1932**	-0.1315	-0.0500	0.1584	-0.0642**	0.0073
ADVICE	—	—	—	0.0624*	0.0040	-0.0510**	—
PROGRAM	-0.2288	0.1348	0.1582	0.2261**	-0.0981	0.1021*	-0.0232
INSURE	-0.2860**	0.2115	0.1533	0.0369	0.1911	0.0079	0.0451**
WATER	-0.0495	-0.0014	0.0658	-0.0191	-0.1253**	0.0270*	0.0134*
SLP	-1.014**	0.3956	0.9089**	-0.3702	-0.2492	0.1694	-0.0034
PISOIL	-0.406	-1.146**	1.712**	-0.0856	0.7448	0.1663	0.1586**
SLOPE	0.3102**	0.3586**	-0.7738**	—	—	—	—
EROTON	—	—	—	-0.0397	0.4190**	-0.0415	-0.0159
RAIN	4.112**	-2.155	-3.11 8**	—	-0.1082	-0.8098*	-0.2551
TEMP	-13.20**	-3.120	20.38**	—	1.560	6.980**	3.748**
PROB(SPRINK)	—	—	—	0.0558	0.3706	0.0614	0.1588**
PROB(GRAVITY)	—	—	—	-0.0018	0.5332**	0.0468	0.1511**

* Significant at the 10-percent level.
** Significant at the 5-percent level.

Note: Elasticities represent a percent change in the dependent variable given a 1-percent change in the mean of the explanatory variable.

significantly less nitrogen than producers who did not receive advice. Perhaps these sources promote fertilizer management techniques that encourage efficient applications of fertilizers. In areas with higher rainfall and lower temperatures, producers applied less nitrogen than producers in warm, more arid regions.

Average crop yields were 6,772 pounds per acre. Irrigation use had a large, positive impact on crop yields. Producers who had a college education or who had crop insurance were also associated with increased crop yields. As expected, more productive soils were associated with large increases in crop yields. However, the overall effect of soil productivity on crop yields greatly depends on whether a producer adopted a sprinkler or gravity system.

The model elasticities are presented in table 7.26. The total factor effect of a 1-percent change in soil productivity on crop yields is -0.023 percent with sprinkler systems and 0.417 percent if a gravity system was used. The total effect of soil productivity on crop yields dramatically changes, given the effect of soil productivity on irrigation decisions.

Cotton in the Albemarle-Pamlico Drainage, Mississippi Embayment, Southern Georgia Coastal Plain, and Southern High Plains

Table 7.27 presents the sample means for cotton producers represented in the Area Studies survey. The cotton sample consisted of 747 observations from the Albemarle-Pamlico Drainage, Mississippi Embayment, Southern Georgia Coastal Plain, and Southern High Plains. Of this sample, 37 percent of producers used irrigation. Changes in percent predicted adoption are shown in table 7.28. The R^2 for the model is 0.25 and the percent correct predictions was 72 percent. The only factors in the model that significantly influenced irrigation adoption decisions for cotton producers were the use of crop rotations, field slope, and weather conditions.

The estimates of pesticide and nitrogen demands and crop yield are presented in table 7.29. The elasticity estimates for the models are presented in table 7.30. Cotton producers are among the most intensive users of pesticides, because of the location of cotton farms

Table 7.27—Sample means from irrigation adoption models for cotton producers in the Albemarle-Pamlico Drainage, Southern Georgia Coastal Plain, Mississippi Embayment, and Southern High Plains

Variables	Means
USE IRRIGATION	.37
COLLEGE	.51
EXPERIENCE	23
WORKOFF	19
TENURE	.28
ACRES	2170
ROTATION	.18
PROGRAM	.95
INSURE	.50
WATERBODY	.44
SLP	136
PISOIL	.73
SLOPE	1.0
WIND	26
RAIN	3.2
TEMP	60
Number of observations	747

Table 7.28—Change in percent predicted adoption of irrigation for cotton producers in the Albemarle-Pamlico Drainage, Southern Georgia Coastal Plain, Mississippi Embayment, and Southern High Plains

Variables	Irrigation use
CONSTANT	-25.073**
COLLEGE	0.0624
EXPERIENCE	-0.0489
WORKOFF	-0.0009
TENURE	0.0107
ACRES	0.0036
ROTATION	0.2262**
PROGRAM	-0.0858
INSURE	-0.0736
WATER	-0.0074
SLP	-0.2002*
PISOIL	0.1762
SLOPE	-0.0582**
WIND	0.0243
RAIN	-3.7871**
TEMP	6.6405**
% predicted adoption:	33.3
% correct predictions:	72.0
Pseudo R^2 [1]	0.25

* Significant at the 10-percent level.
** Significant at the 5-percent level.
[1] Veall and Zimmerman's pseudo R^2.

Note: For the table, the coefficients estimated from the limited dependent model have been converted into change in percent predicted adoption. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, RKLS, WIND, RAIN AND TEMP), the reported value is the change in the percent predicted adoption given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in the percent predicted adoption with a unit change of 0.01 from the variable mean. See Appendixes 2-A and 2-B for further details.

Table 7.29—Estimates of input demand and crop yield effects for cotton producers in the Albemarle-Pamlico Drainage, Southern Georgia Coastal Plain, Mississippi Embayment, and Southern High Plains — Irrigation adoption

Variables	Herbicide use	Insecticide use	Nitrogen use	Crop yield
		lbs/acre		
CONSTANT	-7.759**	-13.5364**	-17.405	-3311.8
COLLEGE	0.2043	0.0864	-1.4837	-3.4190
EXPERIENCE	-0.0096*	-0.0023	0.0188	0.1261
WORKOFF	-0.00005	0.0004	-0.0163	-0.1328
TENURE	0.0782	-0.1496	3.4324	86.393**
ACRES	0.1486**	0.1385**	5.3282**	3.7487
ROTATION	0.0665	-0.1288	10.088**	50.689*
ADVICE	0.1229	0.3470**	-11.133**	—
PROGRAM	0.0137	0.2419	2.8821	44.847
INSURE	-0.4321**	-0.2142*	-9.3834*	5.6046
WATERBODY	0.3326**	-0.0155	10.319**	-11.685
SLP	-0.0037	0.0039**	0.0651	-0.7302*
PISOIL	0.0214	0.1618	18.874*	-138.64*
EROTON	-0.0006	0.0008	0.1288**	-0.0341
RAIN	2.1900**	2.8154**	6.0593	-583.96**
TEMP	—	—	—	1161.3**
PROB(USEIRR)	1.0372**	1.1355**	37.194**	330.87**
Mean of dependent	2.1	1.1	73	584
Adjusted R^2	0.248	0.433[1]	0.266	0.204

* Significant at the 10-percent level.
** Significant at the 5-percent level.
[1] Adjusted R^2 for insecticide use model is from the OLS estimation.
Note: The coefficients estimated from both the insecticide use and yield equations have been converted to the change in insecticide use or yields. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, and TEMP), the reported value is the change in insecticide use or yields given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in insecticide use or yields with a unit change of 0.01 from the variable mean. See Appendixes 7-A and 7-B for further details.

Table 7.30—Elasticity estimates for cotton producers in the Albemarle-Pamlico Drainage, Southern Georgia Coastal Plain, Mississippi Embayment and Southern High Plains — Irrigation adoption

	Adoption model	Chemical input use and cotton yield models			
Variable	Irrigation use	Herbicide use	Insecticide use	Nitrogen use	Crop yield
		lbs/acre			
CONSTANT	-67.38**	-3.668**	-11.96**	-0.2382	-5.666
COLLEGE	0.0848	0.0489	0.0387	-0.0103	-0.0029
EXPERIENCE	-0.1315	-0.1045*	-0.0463	0.0059	0.0050
WORKOFF	-0.0242	-0.0004	0.0068	-0.0042	-0.0039
TENURE	0.0080	0.0103	-0.0369	0.0131	0.0403**
ACRES	0.0097	0.0703**	0.1224**	0.0729**	0.0064
ROTATION	0.1079**	0.0056	-0.0202	0.0244**	0.0151*
ADVICE	—	0.0276	0.1455**	-0.0326	—
PROGRAM	-0.2180	0.0061	0.2020	0.0373	0.0724
INSURE	-0.0983	-0.1016**	-0.0942*	-0.0638*	0.0046
WATERBODY	-0.0088	0.0693**	-0.0060	0.0623**	-0.0090
SLP	-0.5380*	-0.2394	0.4710**	0.1213	-0.1697*
PISOIL	0.4734	0.0074	0.1044	0.1887*	-0.1744*
SLOPE	-0.1564**	—	—	—	—
EROTON	—	-0.0114	0.0282	0.0671**	-0.0021
WIND	0.0653	—	—	—	—
RAIN	-10.178**	3.343**	8.036**	0.2677	-0.9991**
TEMP	17.846**	—	—	—	1.987**
PROB(USEIRR)	—	0.1824**	0.3733**	0.1893**	0.2106**

* Significant at the 10-percent level.
** Significant at the 5-percent level.
Note: Elasticities represent a percent change in the dependent variable given a 1-percent change in the mean of the explanatory variable.

(Greene, 1997). Cotton is generally grown in warmer areas of the United States, and these climates may have greater pest problems, especially in humid areas. The cotton producers in this sample used, on average, 2.1 pounds of herbicide per acre and 1.1 pounds of insecticide per acre.

The factors with the greatest effect on herbicide and insecticide use were average monthly rainfall and the probability of adopting irrigation. Irrigation use had a strong positive impact on pesticide use. The greater the number of acres operated, the greater the amount of herbicide and insecticide applied. Producers who received pest management advice from either a chemical dealer, a local extension service or hired staff also applied significantly more insecticides than those not receiving advice. This result may indicate that producers who seek advice may experience more insect problems, and therefore, would be motivated to use more pesticides. Receiving advice did not affect herbicide use. Increased insecticide use was also associated with increased soil leaching potential of the field. Herbicide use, however, was higher if the field was located near a water body. Producers who had crop insurance had lower herbicide applications.

The amount of nitrogen applied by cotton producers in the sample averaged 73 pounds per acre. Irrigation was associated with greater applications of nitrogen compared with cotton producers who did not irrigate. A unit change in the probability of using irrigation increased nitrogen use by about 37 pounds-per-acre (table 7.29). Increased nitrogen use was also associated with large farms and with farmers who used crop rotations for pest management. Producers who received fertilizer management advice from a fertilizer company, hired consultants or the extension service used significantly less fertilizer than those who did not receive advice. The higher the potential of soil to erode, the greater the application rate of nitrogen.

Cotton yields for the sample averaged 584 pounds per acre. Cotton farmers who owned the field were associated with higher crop yields than those who rent. Crop productivity was also significantly affected by warm, dry weather.

The results of the model showed that the adoption of irrigation had a significant positive effect on cotton yields, in addition to the positive impact on pesticide and nitrogen use.

Summary

We chose specific crops and areas as case studies to explore the relationship between adoption of management technologies, crop yields, and the use of pesticides and fertilizers. The results of the analyses illustrate the wide range of impacts associated with different technologies. Policies designed to encourage the adoption of specific technologies and practices may have both direct and indirect effects on yields and chemical use.

Variables in the analysis of tillage practices used by soybean producers did little to explain variations in herbicide applications. Although many factors were associated with variations in soybean yields, tillage choices had no effect on yields. Concerns that use of crop-residue management systems, such as no-till or other conservation tillage systems, might increase herbicide applications and adversely affect crop yields are not demonstrated in our results. Also, producers who adopted soil conservation practices to protect water quality did not use statistically different quantities of pesticides or nutrients, nor was there a difference in crop productivity. Soil conservation practices specifically designed to protect water quality, rather than maintain soil productivity, typically are placed at the edge of fields. Therefore, these technologies would not be expected directly to influence management decisions for a field.

In the analysis of alternative, pest-management practices adopted by cotton growers, the adoption of pest management practices had mixed effects on crop yields and chemical input use. Three of the four practices we analyzed—biological controls, destroying crop residues, and rotations—had no impact at all on yields or insecticide use. Scouting, on the other hand, had a significant, positive association with chemical use. Perhaps farmers who scout recognize potential pest infestations and problems more frequently than those who do not, and therefore, apply more chemicals to control pests. Without data on infestation levels, this hypothesis could not be tested directly. Corn producers who adopted the practice of destroying crop residues experienced lower insecticide usage than those who had not adopted the practice. However, the other pest management practices we analyzed—scouting and rotations—did not significantly affect insecticide use on corn. Scouting was positively and significantly associated with corn yield. The other two practices, destroying crop residues and rotations, did not significantly affect crop productivity.

Modern nutrient management practices (N-testing, split nitrogen applications, and micronutrient use) did not have a significant impact on the use of nitrogen fertilizer or crop yields, by corn producers in Central Nebraska, Illinois/Iowa Basins, and the White River Basin. Legumes in rotation as a nutrient management practice had no significant effect on nitrogen fertilizer use for corn producers, but did result in higher corn yields. The use of legumes in rotation did not significantly affect nitrogen fertilizer use on a per-acre basis, but corn yield increased, and the amount of chemical fertilizer input per unit of yield declined.

In general, the choice of irrigation technology did not have a significant impact on the use of chemicals, such as pesticides or nutrients, by corn producers in the Central Nebraska River Basin. However, irrigation significantly increased corn yields. Irrigation increased the use of pesticides and nutrients, as well as increased crop yields in the cotton regions of the Area Studies survey. The larger the farm, the more chemicals applied and the higher the crop yields. Pest management advice was associated with increased applications of insecticides. However, fertilizer management advice reduced nitrogen use. While increased rainfall significantly increased chemical use, it had a negative effect on crop productivity.

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Appendix 7-A

Econometric Model: Sample Self-Selection in the Binomial Case

The following econometric approach is used to correct for sample self-selection. The adoption decision and input demand/crop yield components are modeled as a recursive system. The logit adoption model is presented in Appendix 2-A. The equation that is estimated is

$$M = Z'\gamma + \varepsilon \qquad (7A\text{-}1)$$

where M is management technology choice (M=1 for adoption and M=0 for nonadoption), Z is the set of exogenous variable that influence adoption, γ is a vector of parameters, and ε is an error term that includes measurement error and unobserved factors that affect adoption (Amemiya, 1981).

The decision to adopt a particular management technology or practice is assumed to be made over a relatively long time, but farmers make seasonal or annual decisions on the quantity of variable inputs to use in production. We assume that a farmer chooses the amount of variable inputs, given fixed factors, in order to maximize net return per acre (π):

$$\pi = P_y Y(X,M,R) - P_x X \qquad (7A\text{-}2)$$

where output Y is a function of variable inputs X, management technology choice M (a fixed factor in the short-run), and resource endowments R (a vector of fixed factors). P_y and P_x are output and input prices, respectively. Under the standard assumptions of a quasi-concave production function and profit maximization, optimal input use and output supply can be solved as functions of prices and fixed factors:

$$X^* = X(P_y, P_x, M, R) \qquad (7A\text{-}3)$$

and

$$Y^* = Y(P_y, P_x, M, R) \qquad (7A\text{-}4)$$

where X*, and Y* are the choices of X and Y, respectively, that maximize net returns.

In order to estimate equations (3) and (4) there must be variation in each exogenous variable in the sample, which often poses a problem for including prices in the model, since in a cross-sectional survey, farmers experience little difference in input or output prices. If there is enough regional variation in the sample, then there may be price variation because of differences among farms in the proximity to markets. Including dummy variables for geographic region would then account for regional price variations. Other factors that may affect prices among farmers located in the same geographic area include: the time of the year sales were made, credit terms used for sales, and volume of sales. These factors, in turn, are likely to be functions of the size of farming operation, its geographic location, and the management ability of a farm operator. Thus, many of the same farm characteristics that influence technology adoption are also likely to affect input use. Input demand and output supply in a cross-sectional sample can then be modeled as:

$$X^* = C'\beta_1 + \delta_1 M + \nu_1 \qquad (7A\text{-}5)$$

and

$$Y^* = C'\beta_2 + \delta_2 M + \nu_2 \qquad (7A\text{-}6)$$

where C is a set of farm characteristics, including size of operation, human capital of the farm operator, and resource endowments, such as soil quality, climate, and geographic location, β and δ are parameters to be estimated, and ν_1 and ν_2 are error terms.

The econometric model given by equation's (1), (5), and (6) is a recursive system. Estimates of the parameters of equation (1) provides important indicators about factors that drive adoption of new resource-conserving technology. Estimates of the parameters in equations (5) and (6) describe how farm characteristics and technology use affect input demand and output supply. For example, if $\delta_1 < 0$, then technology adoption has resulted in less input use per acre.

The adoption decision that appears as an explanatory variable in equations (5) and (6) may be endogenous. If the error term ε in equation (1) and the error terms ν_1 and ν_2 in equations (5) and (6) are correlated, then estimating equations (5) and (6) using Ordinary Least Squares (OLS) would result in biased estimates of δ_1 and δ_2 (Green, 1990), which is the case if an unobserved factor affects both decisions to adopt technology and to use chemical inputs, i.e., if Z and C were identical.

To address the simultaneity of technology adoption and input use, an instrumental variables approach is used. In this approach, the technology adoption variable M in equations (5) and (6) is replaced by an instrument, in this case, the predicted values of adoption obtained from

$$\text{Prob}(M = 1) = \frac{e^{\gamma' Z}}{1 + e^{\gamma' Z}} \qquad (7A - 7)$$

where e is the exponential function.[7] Using the predicted value of M purges unobserved factors contained in the error term ε in equation (1). The OLS estimates of the parameters to equations (5) and (6) will then be unbiased.

Another consideration is identification. A recursive model is said to be identified if some information included in the instrumental variables is not in the exogenous variables of the model itself. For example, the model would be identified if there is at least one variable in Z that is not in C, since the instrument for M is a function of Z. In the present model, this is not a strict requirement since equation (1) is nonlinear. Thus, the predicted value for M from equation (7) can be used as an instrument for M in equations (5) and (6), even if Z is equivalent to C (Manski, 1989).

In situations where a continuous dependent variable Y is observed only in certain ranges, OLS estimation of the function may give biased results (Maddala, 1983). For example, for some crops in some regions, a significant number of farmers use no pesticide, and the data are said to be *censored*. The tobit model provides an alternative means to find unbiased estimates in these cases. When the number of zero observations on Y is small, OLS and tobit estimates are virtually the same.

Econometric Model: Sample Self-Selection in the Multinomial Case

The multinomial logit form of the adoption model is presented in Appendix 2-A. In the second equation of the recursive model, optimal chemical use, X*, is a function of farm characteristics C and the choice of tillage technology:

$$X^* = C'\gamma_1 + \sum_{j=1}^{J} \alpha_{1j}\tilde{M}_j + \nu_1 \qquad (7A\text{-}8)$$

where $\tilde{M}_j$ is the predicted probability of adoption for technology j, α_1 and γ_1 are vectors of parameters and ν_1 is an error term. The coefficients α_{1j} indicate the difference in chemical use between technology j and the reference technology M_0.

The effect of technology adoption on output or yield Y* is given by:

$$Y^* = C'\gamma_2 + \sum_{j=1}^{J} \alpha_{2j}\tilde{M}_{j+\nu_2} \qquad (7A-9)$$

where α_2 and γ_2 are vectors of parameters and ν_2 is an error term. The coefficients α_{2j} give the effect of adopting technology j on yield Y between technology j and the reference technology M_0. Requirements for the identification of the recursive system with the multinomial logit model are the same as those described for the recursive system with the binomial logit model.

Appendix 7-B

Interpreting Model Results

The technology parameters δ_1 and δ_2 that are estimated for the input demand and crop supply functions require special interpretation (see equations (5) and (6) in appendix 7-A). Because the adoption variable M has been replaced in these equations with an estimate of the probability of adoption, the unit of this variable is changed. As a consequence, the estimates of δ_1 and δ_2 measure the effect of a change in probability of adoption on crop yield or chemical demand. To make interpretation easier, these effects are translated into elasticities calculated at the means of the variables. The elasticity e_{YM} gives the percent change in the dependent variable Y resulting from a 1-percent change in the probability of adoption:

$$e_{YM} = \delta * \frac{\overline{M}}{\overline{Y}} \qquad (7B-1)$$

where $\overline{M}$ is the mean value of M and $\overline{Y}$ is the mean value of Y.

A change in an independent variable X can affect Y two ways. First, it affects Y directly, as measured by the coefficient on X, in the input demand or output supply equation. Second, it affects Y indirectly through the probability of adopting a new technology.

[7] A more detailed interpretation of model results is presented in appendix 2-B.

8. Conclusions

The Area Studies Survey data set offered a unique opportunity to assess the usefulness of conducting a field-level survey linked to site-specific resource characteristics. We have incorporated many of the lessons learned into the ERS/NASS survey program.

The richness of the data set allowed a wide range of analyses. The lack of data on costs and prices, however, greatly handicapped the study. We assumed that a farmer's choice of inputs and outputs reflects an economic decision (i.e., profit maximization), but the lack of explicit cost data meant that we could not directly test the influence of technology costs, input costs, taxes, or cost-sharing policies. Other chemical use and management practices surveys conducted at this time also were not linked to financial data and could provide only incomplete analyses of the adoption of agricultural practices and technologies. Based on results from these survey efforts, ERS and NASS developed the Agricultural Resource Management Study (ARMS) Survey that combined elements of the Area Studies, Cropping Practices, and Costs of Production surveys. For a limited number of crops, the ARMS Survey ties the field-level practice and chemical-use data to the enterprise-level costs associated with producing a crop.

The preceding chapters described the use of selected nutrient, pest, soil, and water-management practices in the 10 watersheds surveyed as part of the Area Studies Project. We determined the factors that influenced the use of a range of management strategies and assessed the impact of technology on crop yields and chemical use. We used a unified analysis framework and a core set of variables in order to make comparisons.

What We Learned About the Factors Influencing Farmers' Use of Management Practices

Several factors emerged as important influences across many agricultural management practices that we studied. Table 8.1 summarizes the findings from chapters 3-6 for the combined-area models.

Education has a significantly positive effect on the adoption of information-intensive technologies, such as the use of biological pest control or nitrogen testing. The increasing complexity of emerging technologies is a factor that agencies or technology providers should consider when targeting potential adopters. Technical assistance, demonstration, or consulting services may be necessary to promote adoption of certain preferred practices.

Information-intensive practices are less likely to be adopted by an experienced farmer, which may imply either that such operators have the knowledge they need to farm successfully or that they are less willing to change practices than younger, less experienced farmers.

Ownership of the surveyed field had less impact on practice adoption than we initially expected, based on the hypothesis that landowners would be more likely to invest in new practices than renters. Most practices included in this study, however, were not structural. Investment in irrigation technologies, which have high initial costs, was more likely for owners rather than renters, but the difference was small.

An enterprise with a livestock component was less likely to adopt information-intensive nutrient management practices, such as soil testing, split nitrogen application or micronutrient use, and more likely to use manure. This expected result may change in the future if livestock operations are required to implement nutrient-management plans that restrict applications of manure to land.

Investment in irrigation had a significant positive effect on the adoption of all pest and nutrient management practices that we considered. Water is the primary transport mechanism for chemicals to leave a root zone and travel to ground or surface water. Therefore, water and chemical management are expected to be complementary. Water management is less predictable for rain-fed agricultural production, so the use of chemical management strategies by such farms may be less effective than for farms that are irrigated.

The influence of the two variables, PROGRAM and ADVICE, warrant further discussion.[1] The policies represented by these variables had a strong positive influence on the adoption of virtually all the preferred soil, pest, and nutrient management technologies. The Area Studies Survey was conducted when conservation compliance was a condition of receiving benefits from a number of U.S. Department of Agriculture programs.

[1] The variable INSURE was meant to be a policy variable designed to capture the element of risk, but it is unclear exactly what the question (as it was worded) actually represents or how the coefficients should be interpreted.

Table 8.1—Change in predicted adoption: Combined area models

Variables	Any soil cons	Soil-water quality	No-till	Rotat.	Resid.	Biolog.	Scout	Modern nutrient	N test	Split N	Legumes	Manure	Decision to irrigate
COLLEGE	+ *				- **	+ **	+ **	+ **		+ **			+ **
EXPERIENCE					- **	- *	- *	- **	- **				- **
WORKOFF			+ *		+ *			- **		- **		- **	- **
TENURE	- **			- *			- **				- **	+ **	+ **
ACRES	+ **		+ **			+ **	+ **	+ **	+ **		- *	- **	- **
ROTATION	+ **	+ **	+ **	na	na	na	na	na	na	na	na	na	+ **
ROWCROP	+ **	+ **	- **	+ ** (soy)	+ ** (cotton)	+ ** (cotton)	+ ** (cotton)	+ **	+ **	+ *	na	+ **	+ ** (corn)
GRAIN	- **			- **	- **	+ ** (frt/veg)	na		- ** (sm-grn)	+ ** (rice/soy)	na		+ ** (frt/veg)
MANURE		+ **	+ *	na	na	na	na	- ** (animal)	- ** (animal)		** (animal)	+ ** (animal)	na
IRRIGATION			- **	+ **	+ **	+ **	+ **	+ **	+ **	+ **	+ **	+ **	na
PROGRAM		+ **	+ **	+ **			+ **	+ **	+ **	+ **	+ **		+ **
ADVICE	+ **	+ **	+ **	+ **	+ **	+ **	+ **	+ **	+ **	+ **			na
INSURE	+ **						+ **	+ **	+ **		- **		
SLP				- **				+ **	+ **		- **		+ **
PISOIL	+ **	+ *		+ **			- *		+ **	- **	+ **	+ **	- ** (slope)
EROTON		+ ** (RKLS)		na	- **	na	na	+ *				+ *	+ ** (wind)
RAIN	+ **	+ *	+ **		+ **			+ **		+ **		na	- **
TEMP	+ **		+ **		+ **	+ **				+ **	na	- **	+

** Significant at the 5-percent level.
* Significant at the 10-percent level.

Farms with an erosion potential in excess of a critical level were required to adopt conservation practices to be eligible to participate in the programs. The availability and use of technical assistance appear to be significant influences on the decision to use the set of practices reviewed in this study. Those subject to conservation compliance likely used some resource-conserving practices, but the significance of ADVICE suggests that technical assistance influenced the choice of the particular practices. The result is an affirmation that extension and education efforts are important components to effect technological change in agriculture. In particular, these activities have an impact on the adoption of information-intensive technologies and on practices that provide offsite benefits.

In the combined-area model for most practices, a regional dummy performed as well as the more precise resource characteristics. The greater significance of the dummies in the combined-area model should be expected because of the usual result that dummies absorb many undistinguishable effects. In the single-area models, however, the resource variables were often significant determinants of adoption, confirming the idea that site-specific information is critical to modeling and explaining resource-conserving efforts. The resource measures that we chose may not have captured the important resource characteristics expected to influence the adoption of all technologies in all watersheds. We did not expect the generic resource characteristics we used to play an important part in a farmer's choice of pest-management strategy. An estimate of pest infestation is a critical resource characteristic in this case. Information on pest pressures is now gathered in current ERS/NASS surveys when possible. We had hoped, however, that constructing site-specific indices would improve the aggregate modeling of adoption for soil, nutrient, and water management practices. We conclude that the value of using field-level resource data is in the single-area or watershed-level modeling efforts. In addition, the chosen index should reflect the environmental circumstances of the specific area and technology, rather than a one-size-fits-all index. For example, in modeling the decision to irrigate, the single attribute, slope, had more explanatory power than did the index of soil productivity.

Assessing the influence of resource characteristics on adoption (i.e., the production-impact) was only one reason to include site-specific resource information in the Area Studies Survey. These data were gathered to provide the link between the economic and physical fate and transport models. That work has not been completed, so it is still unclear whether the micro data are useful to assess aggregate models. The site-specific resource information at the watershed level is important for both *production-impact* and *environmental-impact* analysis.

The combined-area models represent the aggregation across distinct watersheds. From a policy perspective, these results can be misleading. For example, for the adoption of soil-conserving practices, a farmer's experience and whether he or she works off-farm have significant positive effects in the Susquehanna River Basin, but the aggregate model results show no significant effects of these factors. A policy decision to encourage adoption of conservation technologies in Susquehanna would be more efficient if based on site-specific information. On the other hand, in some cases, the combined-area model results are dominated by a single area. The data allow fairly precise environmental-policy modeling to use for targeting. The unified modeling approach that we used shows that important information can be lost in the process of aggregation. Incentives developed to address factors identified in the aggregate model may be appropriate for only one area and counterproductive for others. We recognize that this averaging problem exists for all policies to some extent. However, our comparison of the combined-area and single-area models illustrated the magnitude of the differences between the Area Studies regions.

What We Learned About the Effects of Adoption on Chemical Use and Crop Yield

In chapter 7, we used several cases from the Area Studies Survey data to analyze whether the adoption of selected practices had an effect on chemical use or on crop yield. Proponents of many of the technologies included claim that adoption will result in a decrease in pesticide or fertilizer use. Others claim that farmers do not adopt these practices because crop yields are lower than those obtained using current technologies. We show that, in general,adoption of new technologies results in little reduction in chemical loadings and no yield decreases. In fact, five cases recorded yield increases. Table 8.2 summarizes the results of the impact analysis.

Our conclusions may apply only to the Area Studies Survey data that we analyzed. We had too few observations in most cases to obtain robust results. In particular, the input demand equations have large, unexplained variation. The adoption of certain technologies may reduce loadings somewhat for some producers,

Table 8.2—Effects of adoption on chemical use and yield: Case studies of selected practices, crops, and regions

Practice	Herbicide use	Insecticide use	Nitrogen use	Crop yield
Soil management practices				
Conservation tillage — Soybeans	ns	na	na	ns
Water quality practices — Corn	ns	+	ns	ns
Pest management practices				
Biological controls — Cotton	na	ns	na	ns
Scouting — cotton	na	+	na	ns
Destroying crop residue — Cotton	na	ns	na	ns
Crop rotation — Cotton	na	ns	na	ns
Scouting — Corn	na	ns	na	+
Destroying crop residue — Corn	na	-	na	ns
Crop rotation — Corn	na	ns	na	ns
Nutrient management practices				
Modern practices — Corn	na	na	ns	ns
Legumes in rotation — Corn	na	na	ns	+
Irrigation practices				
Sprinkler irrigation — Corn	ns	ns	ns	+
Gravity irrigation — Corn	ns	+	ns	+
Irrigation — Cotton	+	+	+	+

na is used to indicate that no model was included for that practice/chemical combination.
+ indicates that the adoption of the practice would lead to an increase in the use of the chemical.
- indicates that the adoption of the practice would lead to an decrease in the use of the chemical.
ns indicates that there was no statistically significant effect of practice adoption on the use of the chemical.

but the average effects are not large enough to show up in the results. The chosen technologies were not all designed with chemical-input reduction as the primary attribute. An exception was crop residue destruction, which directly affects pest populations. Use of this practice did result in a reduction of insecticide use. Use of conservation tillage did not result in an increase in herbicide use, at least in the soybean case that we studied. More site-specific observations are necessary to conduct a thorough analysis of adoption impacts.

Summary

The data-gathering stage of the Area Studies Survey was completed in 1995,[2] but several important activities followed. Researchers used the data to analyze selected technologies and regions in depth. This report synthesizes what was learned in those studies and reports a comprehensive study of the entire data set. The results of the Area Studies Project contributed to the decision to merge the ERS Farm Costs and Returns and the Cropping Practices Survey. This integrated survey is the Agricultural Resource Management Study (ARMS) Survey. Now, the adoption modeling can include technology costs and input prices. Many questions used on the Area Studies Survey instrument were incorporated in the integrated survey. In addition, location variables now are included in all ERS survey instruments, which facilitates the use of resource data with more specificity than county averages. The benefits of using a survey at a national level similar to the Area Studies Survey have been incorporated within the current ERS survey program.

The greatest contribution of an Area Studies survey based on field-level characteristics could be to help answer a watershed-specific question. A unified modeling framework was used to compare the results of aggregate and regional studies. Resource characteristics are an important component of producers' decisions. The analyses of farming systems (combinations of agricultural practices) also will be enhanced by site-specific resource data. Both economic and physical modeling efforts can be supported with the data that is produced through the survey. Agricultural water-quality problems are inherently site-specific. Surveys designed to capture national (or even State) averages are not as useful for analysis as those that sample extensively in an area of interest. For environmental problems, analyses will be most efficient if conducted at a geographically relevant scale whenever possible. The Area Studies Project succeeded in developing and conducting a survey that has contributed to our understanding of agricultural-practice adoption and of survey design. During the analysis of the data, we were able to incorporate the lessons that we learned into the current survey program.

[2] The final set of data was received by ERS in March 1995.