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

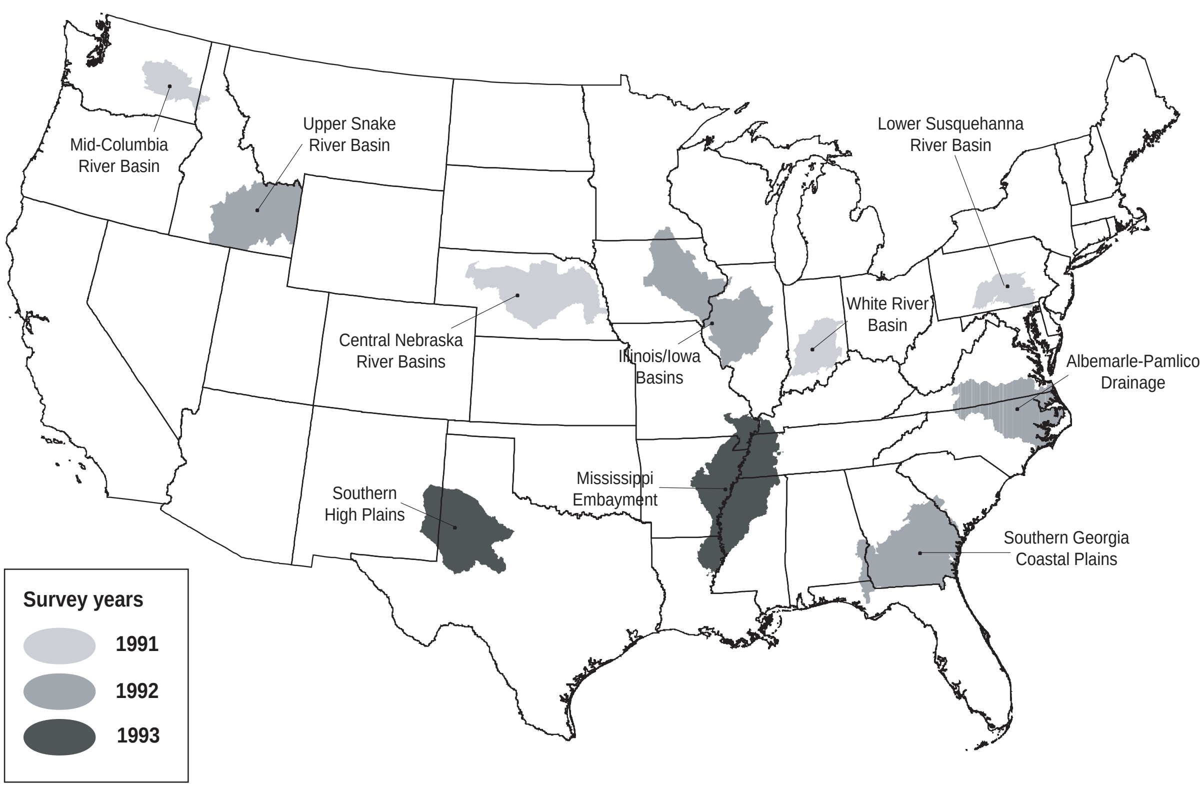
The areas surveyed in 1991 were the Central Nebraska River Basins, White River Basin in Indiana, Lower Susquehanna River Basin in Pennsylvania, and Mid-Columbia River Basin in Washington. The areas selected for the 1992 Area Studies survey were the Albemarle-Pamlico Drainage in Virginia, Southern Georgia 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.

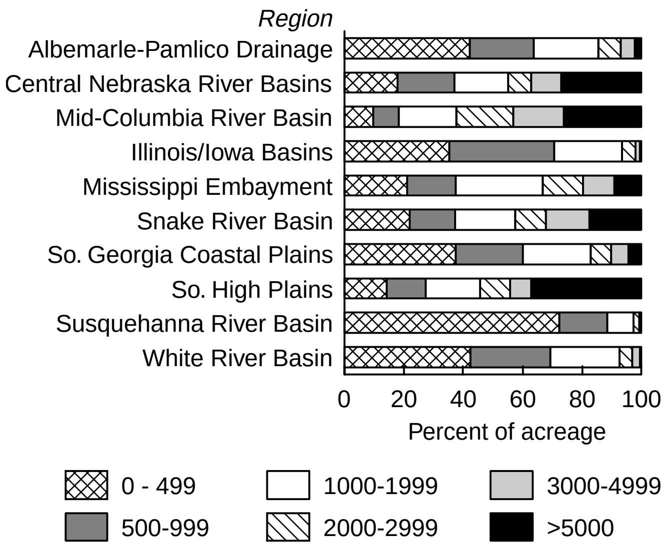
[2] Some crops within the “other crops” category may have large acreage in a specific area but do not comprise a significant portion of the total acreage. For example, potatoes are the main crop in the Upper Snake River Basin, so almost 42 percent of the cropland in this area is designated as “other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

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

	Cropland							Not cropland						
Region	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	Total agricultural 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.

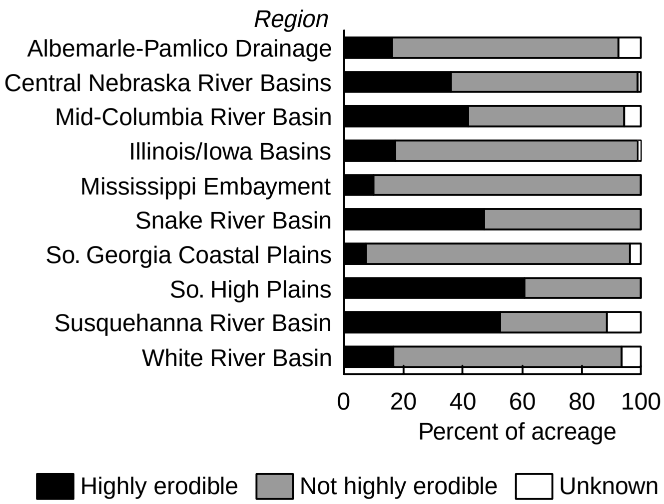
Figure 2.4 illustrates the distribution of leachable soils in the Area Studies regions. As expected, soil leaching potential varies regionally. Of all the areas, the Susquehanna and Illinois/Iowa River Basins had the least amount of agricultural land with high SLP, about 4 and 7 percent, respectively. 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.

[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.

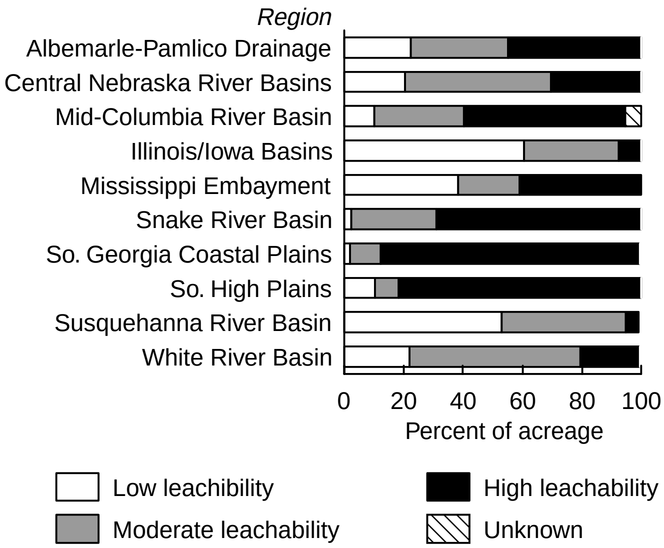
Normative Models

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-

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 differently 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 pre

footnote 6 (continued)
sented 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-

[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.

[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.

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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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:

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

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:

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

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:

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

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:

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

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:

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

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