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Soil, Nutrient, and Water Management Systems Used in U.S. Corn Production

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Abstract

Corn production uses over 25 percent of the Nation's cropland and more than 40 percent of the commercial fertilizer applied to crops. Thus, corn farmers' choices of soil, nutrient, and water management systems can have a major impact not only on their own profitability, but also on the environment. If sound economic and environmental choices are to be encouraged, it may help to assess relationships between operator and farm characteristics and the adoption of management techniques by corn farmers. Data from the 1996 Agricultural Resource Management Survey (ARMS) of U.S. corn farms and producers are analyzed for this purpose, supplemented by a literature survey on factors that influence corn farm management choices. Relationships were found between certain socioeconomic variables, including farmer age and education and size of the operation, and implementation of management practices. This is the first study to relate corn farm management choices, on a national scale, to so broad a set of characteristics.

Keywords: ARMS, soil management, nutrient management, irrigation systems, profitability, socioeconomic variables.

Acknowledgments

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Contents

Summary

Corn grown for grain is the focus of this report because of the large role it plays in American agriculture and its use of agricultural resources—corn is planted to more than 25 percent of the Nation's cropland and annually uses over 40 percent of the commercial fertilizers applied to crops. Each year corn producers make numerous resource management decisions that affect not only their economic well-being, but also the nearby environment. Their choices from among a variety of soil, nutrient, and irrigation water management systems can have a major impact on farm profitability and on the quality and value of environmental resources.

A wide variety of soil, nutrient, and irrigation management practices are available to farmers, most of them concerned with the basic building block of agriculture, the soil. Soil management practices include the tillage and cropping systems and crop rotations used on a farm. Tillage practices, through their impact on soil and chemical movement, are major determinants of agriculture's impact on the environment. Cropping patterns and rotations affect the amounts of chemical or nonchemical fertilizers that are needed.

Conservation tillage was used on about 38 percent of the land in corn production in 1996. Reduced tillage and conventional tillage, practices that leave fewer residues on the soil surface, were used on 30 and 32 percent, respectively, of the planted corn acreage.

Corn farmers using conservation tillage systems tended to be younger and have more years of formal education than those using reduced-till and conventional systems. By most size measures, no-till corn producers farmed larger and less diverse operations than producers using conventional tillage methods, and their farms generated more income. However, the levels of chemical inputs used in corn production were similar across different tillage systems.

Corn farmers' nutrient management decisions influence the amounts and form of nutrients used, the timing of fertilizer application, and the method of application. The mix of these choices influences how much of a nutrient is used by the corn, how much is stored as a residual in the soil, and how much becomes available as a potential water and air pollutant.

Two recommended nutrient management practices, corn-legume rotations (primarily with soybeans) and soil incorporation of nitrogen fertilizer (either through injection application or broadcasting with incorporation), were used on nearly 60 percent of the corn acreage. Soil testing, applying all nitrogen at or after planting, and precision agriculture technologies were each used individually on 20 to 30 percent of the corn acreage. Nitrogen inhibitors were used on less than 10 percent of the acres.

Irrigation management practices for corn production are important because corn has substantially more irrigated land than any other single crop, 10 to11 million acres, or about 15 percent of total corn acreage. Since water is the primary transport mechanism through which agricultural residuals enter the environment, water management decisions have important implications. Irrigators face numerous decisions on the types of water delivery system to use, how to use the water effectively, and which sources of

information to rely on in making these decisions. Groundwater is the major source of water for irrigated corn, used on nearly 90 percent of the irrigated acreage. Gravity flow irrigation systems are used on 42 percent of the acreage, followed by advanced sprinkler systems on nearly 40 percent. Chemical fertilizer was applied to corn through the irrigation system on 17 percent of the irrigated acreage. The most frequently used sources of water information are local irrigation district specialists, neighboring farmers, and irrigation equipment dealers.

These findings are based on the 1996 Agricultural Resource Management Survey (ARMS) of U.S. corn producers, which documents the most common soil, nutrient, and irrigation management systems adopted by corn farmers.

Introduction

This report develops information on resource management practices used by U.S. corn producers. It contributes to the policymaking process that seeks to balance public and private goals related to agriculture and the environment. The report presents findings from the 1996 Agricultural Resource Management Survey (ARMS) of U.S. corn producers, which documents the most common soil, nutrient, and irrigation management systems adopted by corn farmers. The ARMS report linked these physical descriptors of corn production with the economic characteristics of the operating unit on which the corn was grown. Previous surveys of cropping practices provided information on the types and frequency of practices, but included few variables that could be used for economic analysis. The present report describes selected operator, farm, and enterprise characteristics of farms producing corn and, for the first time, links these socioeconomic variables to the management systems.

One reflection of the significant increases in the productivity of U.S. agriculture over the last 50 years is the quadrupling of average corn yields. These yield increases have resulted from a combination of improved seed varieties, greater fertilizer and pesticide use, and improved tillage, rotation, and irrigation practices used in the complex production systems that characterize modern agriculture. However, the same factors that have increased productivity can have negative impacts on the environment, particularly on water quality.

The use of commercial fertilizers, insecticides, herbicides, and fungicides in the United States has increased rapidly in the second half of the 20th century as the predominant form of agriculture has evolved from integrated crop and livestock farming to commercial grain farms. Public concern has been expressed about surface and ground water contamination, soil erosion, pesticide residues in food, and the environmental impact of agricultural chemicals. This has stimulated interest in alternative production systems that are less dependent on chemicals, conserve the soil, and mitigate the loss of nutrients to the environment. However, efforts to reduce pollution from agriculture can have adverse economic impacts on the agricultural community.

Developing policies to reduce both the potential environmental damages attributed to agriculture and the economic impact on farmers requires understanding not only the technologies, but also the factors that influence farmers to adopt practices that could improve the environment. Identifying the farm and operator characteristics associated with specific practices and systems may provide information for targeting education, technical assistance, and cost-sharing programs for nutrient management.

Numerous studies have focused on the potential impact on the environment of various technologies for managing soil, nutrients, and water. However, many of these studies were local or regional in scope and did not provide a national perspective. Others were limited to identifying the practices in use, without addressing the dynamics involved in their selection.

This study of corn production was undertaken to: (1) provide information about the major corn-producing regions of the United States in terms of their management practices, and (2) link this information with variables related to corn producers and the overall economics of their farms. The 1996 ARMS data makes this possible because it links physical field-level descriptors of corn production with the economic characteristics of the entire operating unit on which corn is produced.

The study is part of an ongoing USDA effort to provide information on the technical and economic characteristics associated with the production of major crops. Its focus is on corn raised for grain because of the crop's major use of resources and its importance to agriculture in general. Corn was planted on nearly one-fourth of all U.S. cropland in 1996, on 79.5 million acres (U.S. Dept. of Agriculture, 1997a). Actions taken by corn farmers as they choose from a variety of soil, nutrient, and water management systems can have a major impact on both profitability and environmental quality. The production of corn is associated with the use of large amounts of chemicals, and water is the primary transport mechanism that moves chemicals and sediments from the field to the environment. Information on soil, nutrient, and water management is essential for an understanding of the relationships between agriculture and the environment and for developing policies to improve these relationships. The management of surface water flow and drainage is an important conservation tool for non-irrigated as well as irrigated corn production. Approximately 14 percent of total corn acreage was irrigated in 1992 and 15 percent

in 1997 (U.S. Dept. of Commerce, 1994; USDA, 1999b).

Much of U.S. corn is grown on or near environmentally sensitive land, requiring intensive management to avoid sediment or chemical transport. For example, in 1995 about 20 percent of the corn was grown on acreage designated as highly erodible land (HEL), and additional corn was produced near wetlands, shallow aquifers, rivers, and streams (USDA, 1997b). Nearly 44 percent (4.9 million nutrient tons) of all commercial nitrogen fertilizer used in 1992 in the United States and 45 percent (1.9 million nutrient tons) of phosphate fertilizer was applied to corn acreage (Lin et al., 1995).

Some agricultural production practices may have negative environmental impacts. Nitrogen from agricultural runoff entering either ground or surface water can diminish drinking water quality; phosphorus in surface water can lead to eutrophication; and volatilization of ammonia fertilizer can contribute to greenhouse gases. While it is difficult to trace the exact source of nonpoint pollution, production agriculture has been implicated as a leading cause of impairment of the Nation's rivers, streams, and estuaries (U.S. Environmental Protection Agency, 1995 and 1998). The Chesapeake Bay and Gulf of Mexico have experienced degradation due primarily to elevated levels of nitrogen and/or phosphorus (U.S. Environmental Protection Agency, 1995; Antweiler et al., 1995). Some groundwater resources, especially from shallow aquifers, have also been found to contain nitrates linked to agricultural sources, often in irrigated crop production areas (CPNRD, 1998). The public has an interest in protecting the quality of water resources, which are affected by the agricultural practices and technologies adopted by producers. All farmers, of whom corn growers are a significant share, will be encouraged by public policies, educational programs, and economic incentives to adopt improved soil, nutrient, and irrigation management practices to conserve resources and reduce risks to the environment.

Objectives and Approach

This report describes U.S. corn production with regard to soil, nutrient, and irrigation management practices and links these practices with operator and farm characteristics. The information provides an objective baseline of the extent to which various agricultural production practices have been adopted. This then provides a basis for further analysis of the factors that influence the decision to adopt specific management practices for corn production.

Following a description of the data and methodology, there is a brief overview of the literature on the adoption of management systems for soil, nutrients, and water, with a more detailed review in appendix A. Information from the 1996 ARMS survey of corn producers, characterizing corn production practices, is then presented. Relationships between soil tillage, nutrient, and water management practices will be used as the focus of the analysis. From the key relationships identified, suggestions for future research on the factors aiding or hindering adoption of these management practices will be made. (Pest management issues are not included in this analysis because the data on pest management practices for corn in 1996 are presented in *Pest Management in U.S. Agriculture*, Fernandez-Cornejo and Jans, 1999).

ARMS Data and Analytical Methodology

As noted, data for this study are from the 1996 Agricultural Resource Management Survey (ARMS). The ARMS is USDA's primary instrument for data collection on a broad range of issues related to agricultural resource use and costs and farm sector financial conditions. The ARMS is a cooperative project between USDA's Economic Research Service (ERS) and National Agricultural Statistics Service (NASS), designed to collect data to support the ERS and NASS estimation programs and the ERS research program on economic and environmental topics. Each year, producers in the States growing the primary field crops (corn, soybeans, wheat, potatoes, and cotton) are surveyed regarding their cropping practices. The 1996 ARMS also included a separate farm-level economic survey of U.S. producers of corn for grain, which provided detailed data on corn production practices and costs and farm financial conditions. Data from the two surveys were combined to create a national dataset of the soil, nutrient, and irrigation management practices used in corn production and to begin identifying some relationships between socioeconomic factors and the adoption of these management practices.

Sampling and data collection for the corn version of the ARMS involved a three-phase process (Kott and Fetter, 1997). Phase 1 involved screening a sample of producers to identify farms that produced corn for grain. For phase 2, production practice and cost information was collected on a randomly selected cornfield from the acreage of each corn producer in the sample. Respondents to the phase 2 interview were questioned in phase 3 about farm financial conditions such as income, assets, and debt. Data in phases 2 and 3 establish the link between agricultural resource use and farm financial conditions, a cornerstone of the ARMS design. It is these data that are described in this report.

The analyses of soil management and nutrient management systems are based upon a sample of 950 corn producers. The analysis of irrigation management is based upon responses from 64 producers in Nebraska, Kansas, and Texas identified in the overall sample of 950 corn growers as irrigators of corn. Respondents in all phases of the 1996 ARMS operated farms in 16 States, aggregated into 4 geographic regions: the Corn Belt, the Lake States, the Plains States, and the Southeast.[1] Each sampled farm represents a number of similar farms in the population, as indicated by its expansion factor, or survey weight, determined from the selection probability of each farm.

[1]Regional designations are: Corn Belt—IL, IA, IN, OH, and MO; Lake States—MI, MN, WI, and PA; Plains States—NE, KS, SD, and TX; and Southeast—KY, NC, and SC.

Literature Highlights on the Adoption of Management Practices and Systems

The literature on the adoption of soil, nutrient, and irrigation management practices and technologies was surveyed to determine which factors might be expected to influence farmers' choices. Some of these factors are identified in the ARMS dataset and can be used to help develop hypotheses for future analyses. Brief highlights from the literature follow, with a more detailed literature review in appendix A. All these studies of conservation technology adoption agree that the probability a practice will be adopted increases as its profitability increases relative to practices in use. Other factors identified as potentially important influences on adoption were size and location of the farming operation and age, education, and managerial capacity of the farm operator.

Numerous studies have identified a variety of economic, demographic, geographic, and policy variables that affect the adoption of conservation tillage and other conservation practices in the United States. Management complexities and profitability are key factors impeding the adoption of conservation tillage. The consensus of many studies is that the relative economic performance of any conservation tillage practice depends on a number of site- and operator-specific factors. Variables found to influence the choice of tillage practices include operator characteristics such as degree of risk aversion and level of managerial expertise and physical characteristics of farms like soil type, topsoil depth, cropping systems, and local climatic conditions.

The studies surveyed found that the factors explaining the adoption of nutrient management practices are regional and practice-specific. Adoption depends on the type of farming in the region (irrigated or not), the type of soils, and the presence of regulation. Some tests, such as manure testing for its nutrient content, may more commonly be done on farms that have a livestock component. It is also probable that operators who believe a nutrient problem exists in their own or their community's drinking water would be more likely to practice improved nutrient management, but this hypothesis has not been tested. There appears to be no single nutrient management practice or set of practices likely to be adopted nationwide. Rather, farm operators will choose among techniques appropriate for their farming systems, soils, and the type of regulation that applies to their area.

Many studies have examined the economic relationships and field conditions associated with the adoption of improved irrigation technologies. The most significant influences appear to be land quality and water cost savings. Included in most of the studies is a marginal water cost based upon the water-use efficiency of alternative technologies, which helps explain why producers select advanced water management technologies.

Characteristics of Farms Producing Corn

In 1996, 69 million acres, comprising nearly one-fourth of U.S. cropland, were planted to corn, on 363,000 farms. Farms growing corn averaged around 600 acres, with the largest average size in the Plains States (table 1 and fig. 1). On all farms producing corn, corn was planted to the most acreage, followed by soybeans (fig. 2). There are regional variations; corn and soybeans account for about the same acreage share in the Corn Belt, for example. However, the importance of irrigated corn in the Plains States is reflected in its large share of acreage. Similarly, the relative importance of other crops, such as cotton and peanuts on farms raising corn, are reflected in the Southeast (fig. 3). As would be expected, corn is raised on a larger share of farms in the Corn Belt than in any other region, 45 percent (fig. 4). Over 50 percent of the acreage was rented, with cash rent predominant in all regions except the Corn Belt (fig. 5). The average gross cash sale from farms raising corn was $162,000, with crop sales accounting for over 50 percent of total sales (fig. 6). Fifty percent of the farms had sales of $100,000 or more, and 6 percent had sales greater than $500,000 (fig. 7). The gross cash income of farmers raising corn was over $160,000 and the net farm income exceeded $40,000. The average balance

Table 1—Regional distribution of corn acreage by crop pattern[1]

Crop pattern	Corn Belt	Lake States	Plains States	Southeast	Total
			1,000 acres		
Nonirrigated:					
Corn-corn	3,995	2,041	868	136	7,040
Corn-soybeans	25,428	6,091	3,912	1,824	37,255
Corn-fallow	3,285	4,144	2,072	330	9,832
Corn-other crops	973	1,723	1,605	356	4,656
Irrigated:					
Corn-corn	d	d	6,003	2	6,005
Corn-soybeans	1,703	211	623	22	2,559
Corn-fallow	187	d	986	d	1,174
Corn-other crops	d	179	84	d	263
Total	35,571	14,389	16,153	2,672	68,785

[1]Corn Belt includes IL, IA, IN, OH, and MO; Lake States are MI, MN, WI, and PA; Plains States are NE, KS, SD, and TX; the Southeast is KY, NC, and SC.
d-insufficient data for disclosure.
Source: Estimated from the 1996 Agricultural Resource Management Survey (ARMS).

Figure 1
Average acreage of farms raising corn for grain, by region

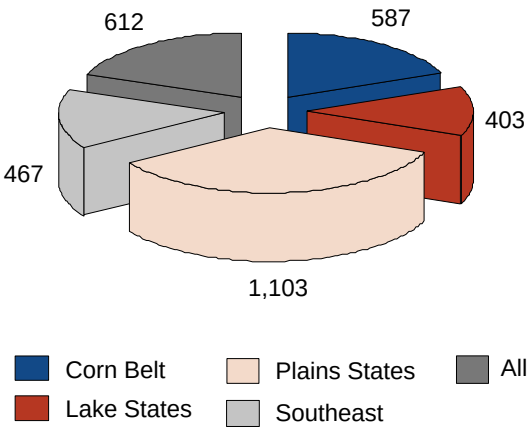


Figure 2
Crop composition on average farm raising corn

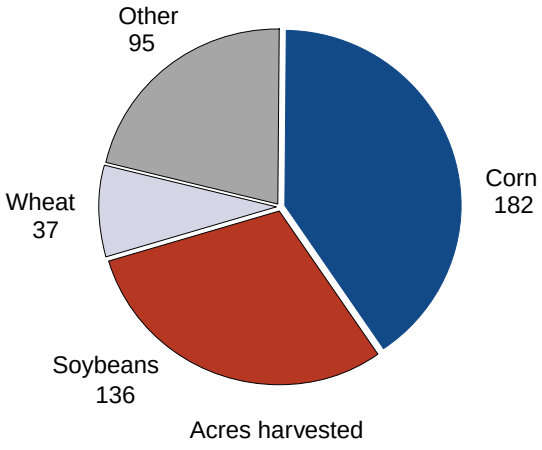


Figure 3
Share of acres harvested for major crops on farms producing corn, by region

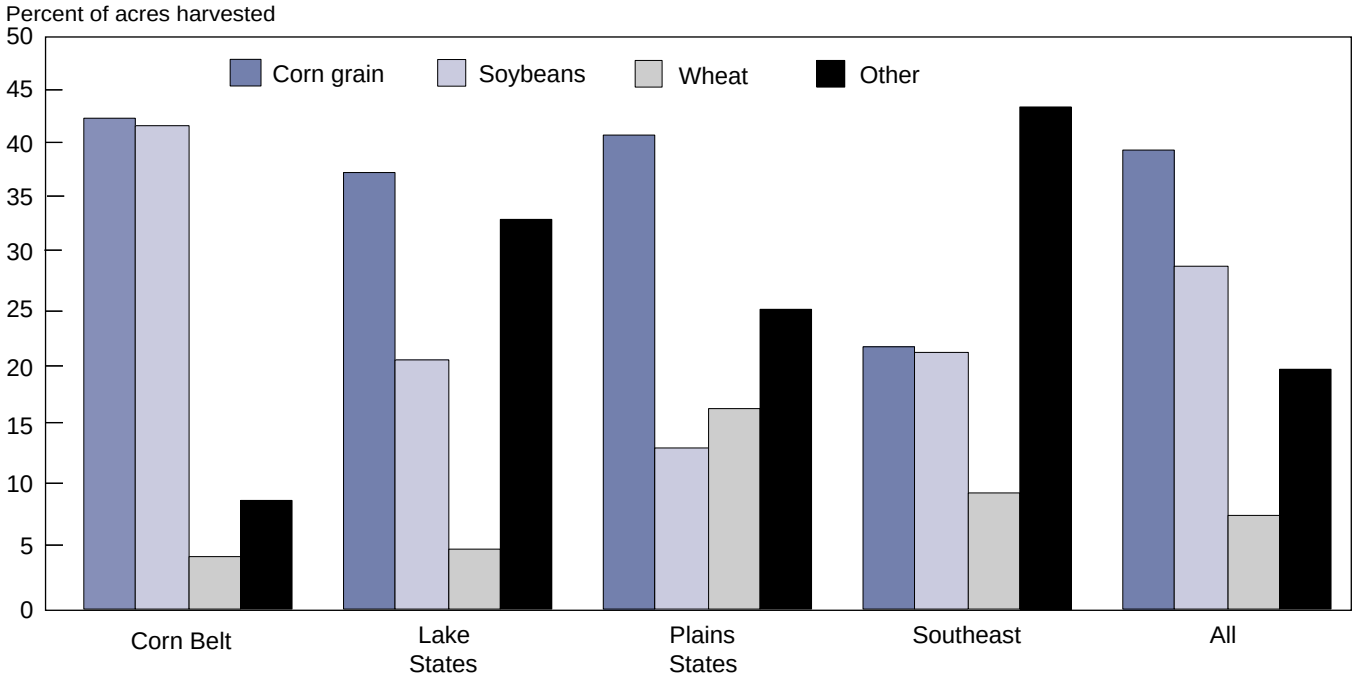
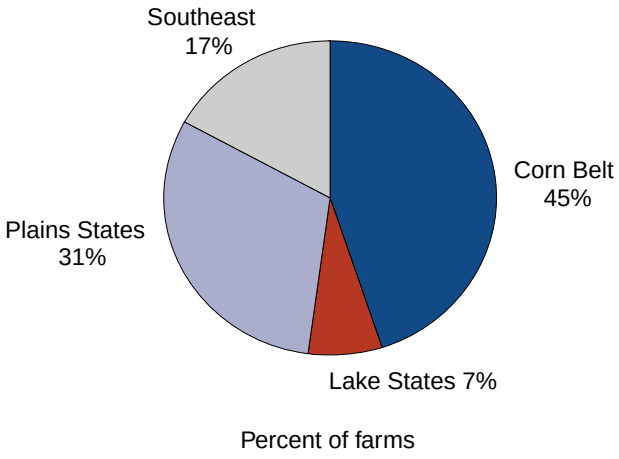


Figure 4
Percent of farms growing corn, by region
The Corn Belt has the largest share



sheet appears favorable, with assets approaching $700,000 and equity approaching $600,000 (fig. 8). Over 40 percent of corn farmers had attended or completed college (fig. 9).

Corn production involves a complex management system and myriad decisions that affect technical, economic, and environmental factors. Some of these choices can be made singularly, but most require consideration of numerous interactions. For example, choices about tillage or crop rotation practices influence, or are influenced by, those made about nutrient and pesticide management. Similarly, irrigation decisions are intertwined with nutrient and soil management decisions. The following sections discuss the use of soil, nutrient, and irrigation management systems in corn production in the major corn-producing regions of the United States.

Figure 5
Tenure composition of farms producing corn, by region

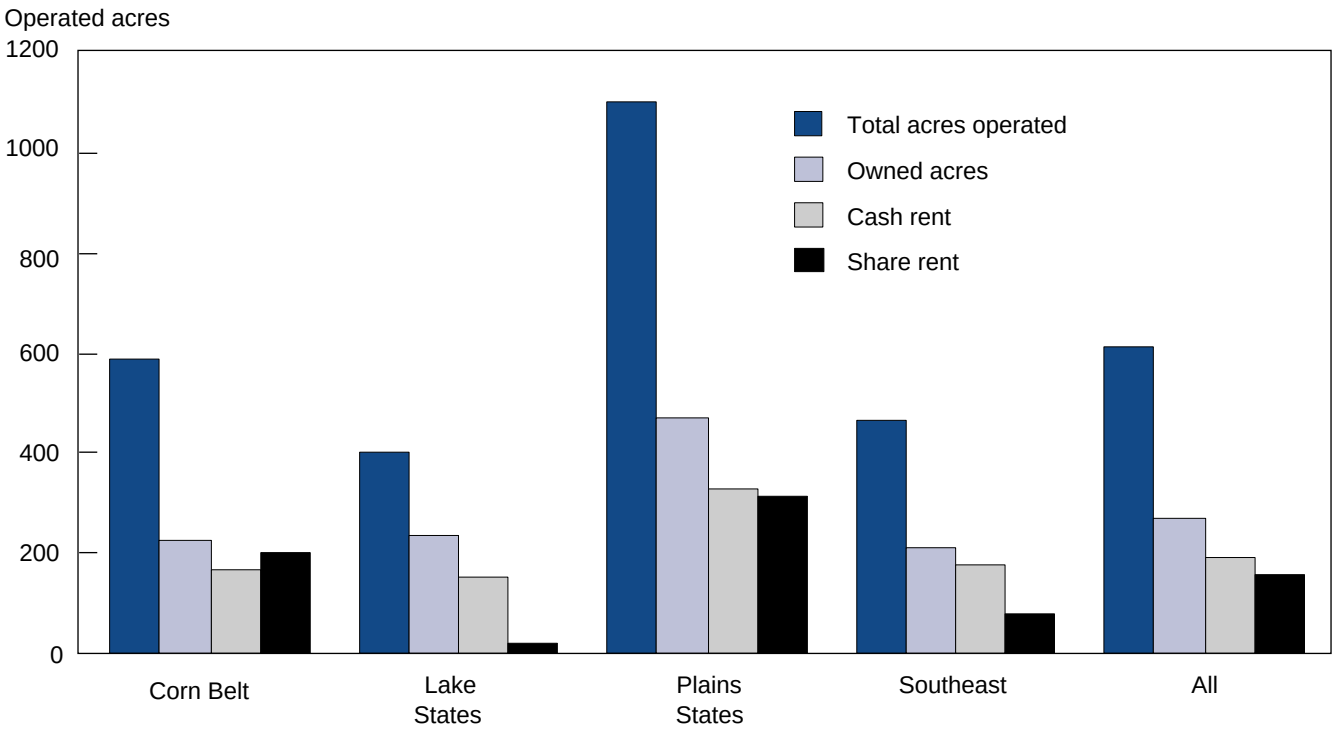


Figure 6
Source of cash sales on farms raising corn
Crop sales were the largest share

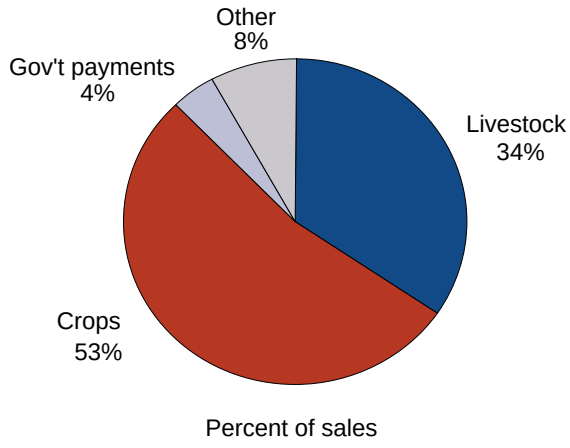


Figure 7
Income from sales on farm raising corn
50 percent of farms have sales of $100,000 or more

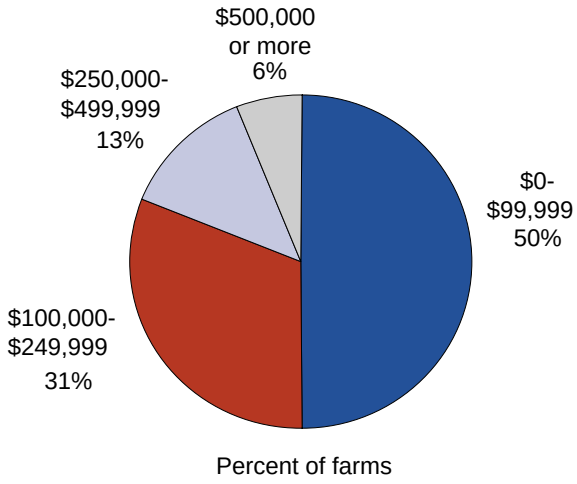


Figure 8

Income and balance sheet information for average farm raising corn

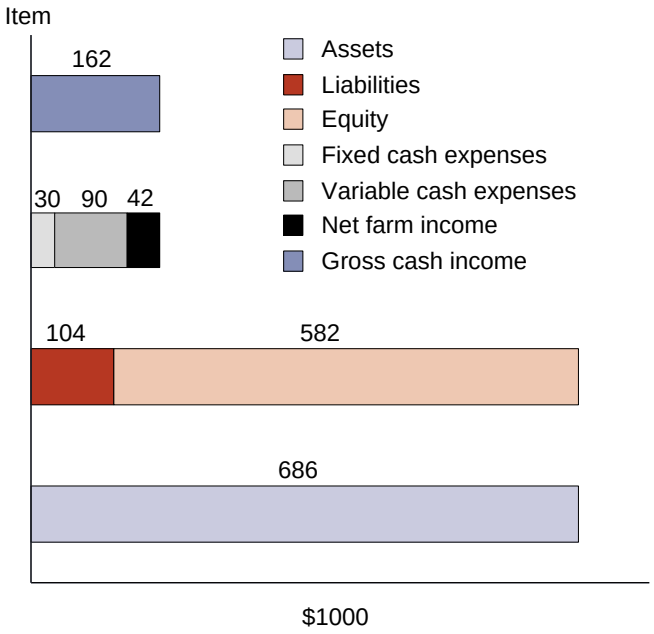
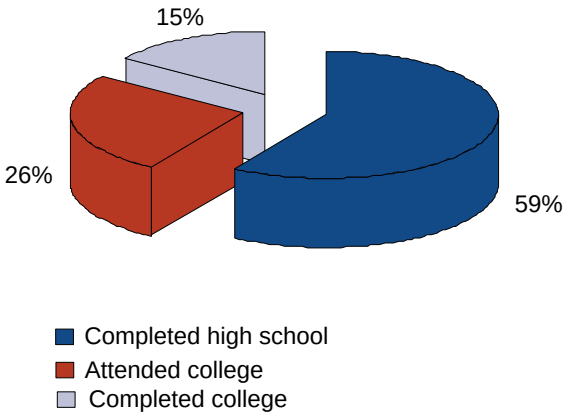


Figure 9

Percent of corn farmers by education

Over 40 percent attended or completed college



Soil Management Systems in Corn Production

Soil is the key resource in all crop production. Beyond supporting the basic physical, chemical, and biological processes for plants to grow, it regulates water flow between infiltration, root-zone storage, deep percolation, and runoff and acts as a buffer between production inputs and the environment. Soil management is an important component of corn production because of its beneficial impacts on soil erosion and topsoil loss, organic content, soil compaction, acidification, and the loss of nitrate, phosphorus, pesticides, salt, and trace elements to surface and groundwater supplies. Hence, the selection by corn producers of soil management practices can have a significant impact on input use, productivity, output, and costs and returns, as well as on environmental quality.

The soil management practices included in the survey are designed to maintain the quality and long-term productivity of the soil and to reduce potential environmental damages from crop production. They include using cover crops and crop rotations and maintaining crop residues on the soil surface. They also include various field structures and buffer zones, such as grass waterways, terraces, contour farming, stripcropping, underground drainage outlets, and surface diversion and drainage channels. Many of these practices may be used in combination, depending on topographic and agriclimatic conditions. The extent to which particular soil management practices are adopted depends on site-specific soil and climate conditions, as well as on technical and economic feasibility and farmers' attitudes toward the practices.

Crop Production Systems

Crop production systems comprise combinations of crop rotations, and crop production and soil conservation practices. These systems are important to soil management, particularly among producers searching for production methods that depend less upon chemicals, conserve soil, and mitigate the loss of nutrients to the environment. Before commercial fertilizers, crop rotations were the primary means of replenishing soil nutrients. Crop rotations take many forms, including a monoculture rotation, where there is continuous production of the same crop, such as corn or cotton, in the same field year after year. Crop rotations may be repeated in a rigid pattern or a flexible one that varies from year to year, or even within a season, to accommodate changes in climatic and market conditions. There can also be an intensive rotation within a year, or a season, under favorable agriclimatic conditions. Cropping systems are designed with differences in soil and climate in mind as well as the socioeconomic conditions under which the crops are produced (see box for "Crop Rotation Definitions").

Crops are rotated to: (1) improve fertility by including nitrogen-fixing legumes in crop rotations, reducing the subsequent need for commercial nitrogen fertilizer, (2) control insects, diseases, and weeds, (3) reduce soil erosion and related loss of soil nutrients and moisture, (4) increase water-holding capacity of the soil through increased organic matter, (5) reduce the water pollution often associated with runoff and leaching, and (6) promote crop diversification to provide an economic buffer against price fluctuation for crops and production inputs.

A corn-legume rotation was used on almost 60 percent of the 1996 corn acres. Continuous corn was the rotation on 19 percent of the acreage. Use of a corn-legume rotation was highest in the Corn Belt, on 82 percent of the acreage, reflecting the common corn-soybean rotation used in that region. Continuous corn was practiced on 44 percent of Plains States acreage, where there is considerable irrigation. Cover crops can hold nitrogen in the root zone during the winter, lessening ground water contamination and also preventing soil erosion. Crop rotations can also prevent or reduce average annual soil loss through planting soil-conserving crops in a rotation with erosive row crops.

Cropping patterns adopted by corn farmers vary by region. Corn-soybean rotations and continuous corn are the most widespread (75 percent of the total nonirrigated acres), practiced by corn growers on nonirrigated corn acreage in all four regions (table 1 and fig. 10). Most of the continuous corn production on nonirrigated acreage took place in the Corn Belt and Plains States, with 57 and 29 percent of the total U.S. corn acreage, respectively, farmed in this pattern.

The Corn Belt is the leading region for the corn-soybean-corn pattern on nonirrigated corn acreage (with 68 percent of the total U.S. nonirrigated corn acreage in this rotation), followed by the Lake States region

Crop Rotation Definitions

These definitions are applied to the 3-year crop sequence data reported for each sample field in the Agriculture Resource Management Survey (ARMS) in order to estimate the crop rotation. The data were limited to the 1996 crop plus the crop planted the previous 2 years on the same field.

Monoculture or continuous rotation—A crop sequence where the same crop is planted for 3 consecutive years in the same field. Small grains (wheat, oats, barley, flax, or rye) or other close-grown crops may be planted in the fall as a cover crop.

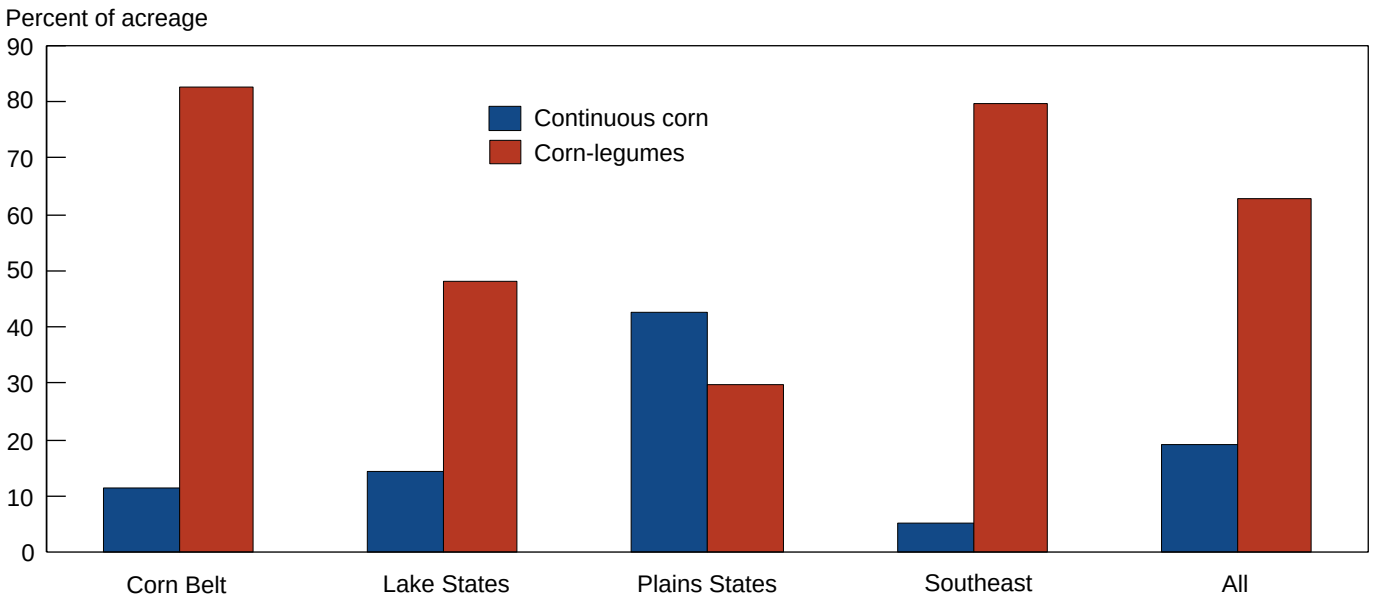
Continuous row crop rotation—A crop sequence, excluding a continuous rotation, in which only row crops (corn, sorghum, soybeans, cotton, peanut, or vegetables) are planted for 3 consecutive years. Small grains or other close-grown crops may be planted in the fall as a cover crop.

Mixed row crop and small grain rotation—A crop sequence where some combination of row crops and small grains are planted over the 3-year period. Rotation excludes soybeans double-cropped with winter wheat.

Hay, pasture, or other-use rotation—A crop sequence that includes hay, pasture, or other use in 1 or more previous years. This rotation excludes any of the rotations listed above and any area that was idle or fallow in 1 of the 2 previous years.

Idle or fallow in rotation—A crop sequence that includes idle, diverted, or fallow land in 1 or more of the previous years.

Figure 10
Cropping patterns in corn production, by region
Corn-legume rotation is the most common



(16 percent). In the Plains States, however, only 11 percent of the nonirrigated corn acreage was planted in rotation with soybeans. A corn-fallow-corn rotation is popular in the Lake States and Corn Belt, with 42 and 33 percent of the total acreage in this rotation. In the Plains States, the share of acreage in this rotation is 21 percent. On the remaining nonirrigated U.S. corn acreage, corn is rotated with sorghum, wheat, cotton, peanuts, rye, and oats.

Crop rotations used on irrigated corn acreage vary by region. The Plains States have 60 percent of the total U.S. irrigated corn acreage, primarily in a continuous corn rotation. The corn-soybean-corn rotation is the most popular in the Corn Belt, where it is practiced on 18 percent of the total U.S. irrigated corn acreage. The share of irrigated corn in the Plains States that use this rotation is only 6 percent. A corn-fallow-corn sequence occurs mostly in the Plains States, where it accounts for 10 percent of the total U.S. irrigated corn acreage. On the remaining irrigated corn acreage, corn is rotated with other crops (table 1).

Crop Residue Management

Crop Residue Management (CRM) refers to the use of tillage and cultivation practices designed to retain crop residue on field surfaces. CRM is in contrast to conventional tillage methods, which typically leave less than 15 percent of residue on the soil surface. CRM has a number of site-dependent beneficial effects, on and off the farm. These include: (1) reduced erosion and chemical runoff, (2) improved moisture retention in soil and better water penetration, (3) increased sequestration of soil organic carbon (some of which might otherwise be released to the atmosphere as carbon dioxide), (4) improved long-term productivity of the soil, and (5) potentially higher economic returns. Crop residue management practices include reduced-tillage and three conservation tillage methods: mulch-till, ridge-till, and no-till. These practices are often combined with off-season cover crops and field-level structural measures for control of erosion (see box, "Tillage Practice Definitions").

Conservation tillage was not the major tillage system in corn production in the United States in 1996. Over 60 percent of the corn acreage was in either conventional (30 percent) or reduced-till systems (32 percent), with the balance split between mulch- and no-till. Ridge-till was used on only 2 percent of the total corn acreage (table 2 and fig. 11). A primary use of ridge-till is to create furrows for water flow in irrigated corn production. There are some regional differences in the adoption of tillage systems for corn production (table 2). In the Lake States, conventional tillage was predominant, used on almost half (46 percent) of the total corn acreage. This share was nearly equal to that of reduced- and mulch-till combined. No-till made up a very small proportion of Lake States corn acreage, and ridge-till was not practiced at all. Conventional tillage was also the predominant practice in the Southeast, used on 37 percent of corn acres, followed closely by no-till at 35 percent. In the Corn Belt, reduced-till was the principal practice, used on 42 percent of regional acreage, with the remaining acreage dominated by conventional tillage systems. Only in the Plains States were tillage practices distributed fairly evenly among conventional, reduced, and conservation tillage, with ridge-till at 6 percent of the regional total (fig. 12).

About 20 percent of the acreage in corn production in 1996 was identified as highly erodible land (HEL) (table 3), and conservation tillage methods were frequently used on these fragile acres. All four regions have about the same share of corn acreage in HEL, 20 percent, indicating that productivity-damaging erosion is a potentially serious problem across corn-producing areas. On 85 percent of HEL acres in corn production, a tillage practice was used that left more than 15 percent residue on the surface, that is, tillage by other than a moldboard plow. For the corn area as a whole, the shares of HEL in reduced-till, mulch-till, and no-till are just about equal. Mulch-till was the most common HEL option in the Lake States, Plains States, and Southeast, while for the Corn Belt reduced-till and no-till were equally practiced. The 1985 Farm Bill and its successors have encouraged the adoption of crop residue management (CRM) on HEL by tying USDA program benefits to implementation of the USDA-approved soil conservation management plan (USDA, 1977b, p. 299). CRM tillage practices have been adopted in response to environmental concerns as well as to economic and public policy incentives (figs. 13 and 14).

Tillage Practice Definitions

Conventional Tillage (< 15% residue)

Tillage types that leave less than 15 percent crop residue cover after planting, or less than 500 pounds per acre of small-grain-residue equivalent, throughout the critical wind erosion period. Generally, this includes use of a moldboard plow or other intensive tillage. Weed control is accomplished with herbicides and/or cultivation.

Reduced Tillage (15 – 30% residue)

Tillage types that leave 15-30 percent crop residue cover after planting, or over 500-1,000 pounds per acre of small-grain-residue equivalent, throughout the critical wind erosion period. It excludes the use of mold-board plow, and the intensity of tillage is reduced. Weed control is accomplished with herbicides and/or cultivation.

Conservation Tillage

Any tillage and planting system that covers 30 percent or more of the soil surface with crop residue, after planting, to reduce soil erosion by water. Where soil erosion by wind is the primary concern, any system that maintains at least 1,000 pounds per acre of flat, small-grain-residue equivalent on the surface throughout the critical wind erosion period. Two key factors influencing crop residue are: (1) the type of crop, which establishes the initial residue amount and its fragility, and (2) the type of tillage operations up to and including planting.

Conservation tillage systems include:

No-till—The soil is left undisturbed from harvest to planting except for nutrient injection. Planting or drilling is accomplished in narrow seedbeds or slots created by coulters, row cleaners, disk openers, in-row chisels, or rototillers. Weed control is accomplished primarily with herbicides. Cultivation may be used for emergency weed control.

Ridge-till—The soil is left undisturbed from harvest to planting except for nutrient injection. Planting is completed in a seedbed prepared on ridges with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges. Weed control is accomplished with herbicides and/or cultivation. Ridges are rebuilt during cultivation.

Mulch-till—The soil is disturbed prior to planting. Tillage tools such as chisels, field cultivators, disks, sweeps, or blades are used. Weed control is accomplished with herbicides and/or cultivation.

Soil and Water Conservation Structures

Soil and water conservation structures can significantly reduce erosion caused by water runoff. These structures allow for surface water to be captured onsite or slowed and diverted from the field via erosion-resistant waterways, channels, or outlets. While crop rotation and tillage practices may also be used to help control erosion, they may be ineffective at controlling runoff water after heavy rains. Therefore, engineered structures are often important components of farm soil management systems.

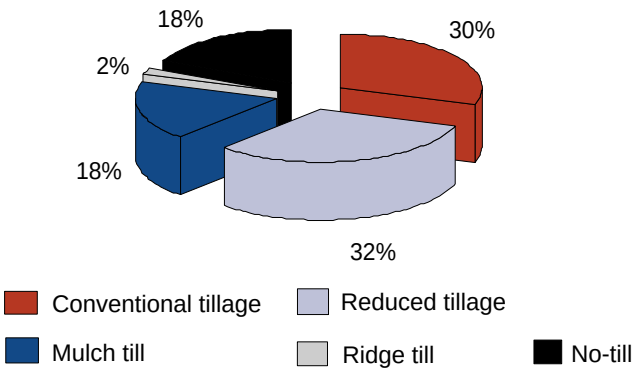
The use of engineered structures for soil and water conservation is widespread in corn production (table

Table 2— Tillage systems used in corn for grain production

Item	Unit	Corn Belt	Lake States	Plains States	Southeast	Total
Acreage	Thousand acres	35,571	14,390	16,153	2672	68,786
Residue	Percent	26	23	34	33	28
Tillage system:						
Conventional	Percent	26	46	25	37	30
Reduced	of acres	42	18	26	13	32
Mulch-till		14	24	21	15	18
No-till		18	12	22	35	18
Ridge-till		0	0	6	0	2

Source: Estimated from the 1996 Agricultural Resource Management Survey (ARMS).

Figure 11
Percent distribution of corn tillage practices



4). In total, 66 percent of planted corn-for-grain acres have at least one of the six soil and water conservation structures included in the survey (fig.15). The presence of these structures varies from one region to another. The Corn Belt (79 percent of regional acreage) and Lake States (75 percent) use such structures more than the Southeast (52 percent) and Plains States (32 percent). Climatic and landscape conditions may be responsible for much of the difference in the use of conservation structures across regions.

Figure 12
Tillage systems used in corn production, by region

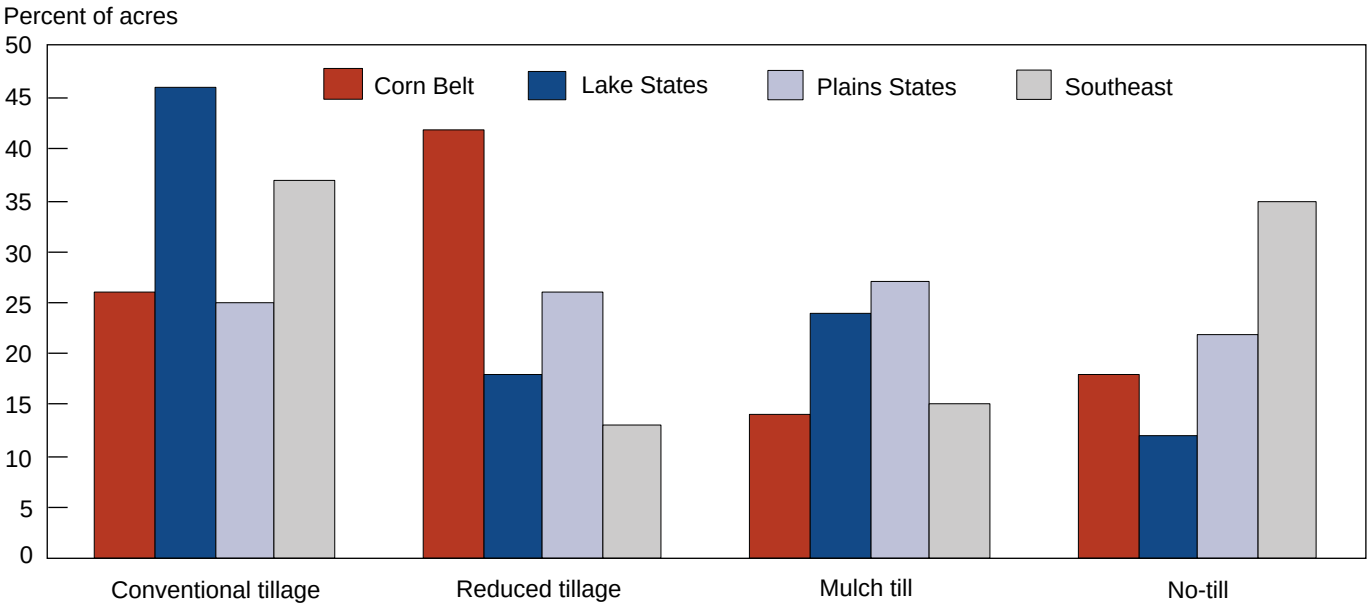
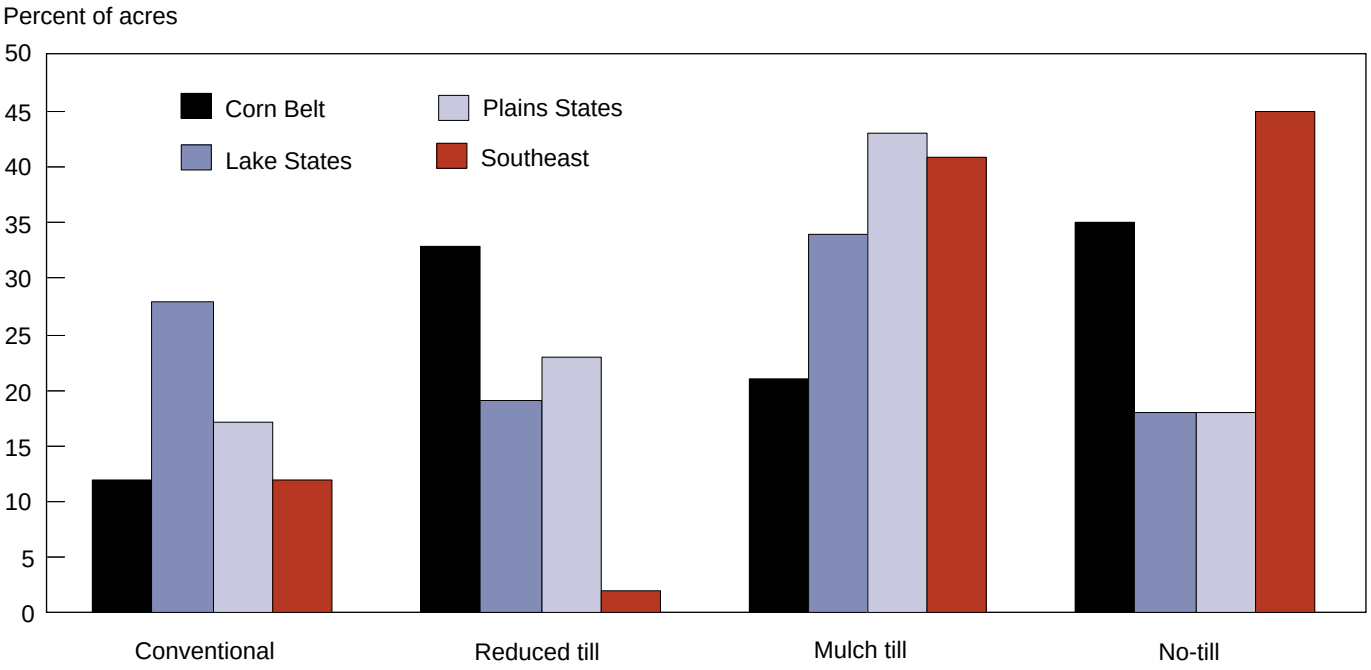


Table 3—Tillage systems used in corn for grain production by soil erodibility classification, 1996[1]

Item	Unit	Corn Belt		Lake States		Plains States		Southeast		Total	
		NHEL	HEL	NHEL	HEL	NHEL	HEL	NHEL	HEL	NHEL	HEL
Acreage	1,000 acres	26,110	9,458	12,820	1,568	12,570	3,578	2,160	512	53,670	15,120
Tillage system:	Percent of										
Conventional	acres	31	12	48	28	27	17	43	12	35	15
Reduced		45	33	18	19	27	23	16	2	33	28
Mulch-till		12	21	23	34	15	43	9	41	15	28
No-till		12	35	11	18	23	18	32	45	15	29
Ridge-till		0	0	0	0	8	0	0	0	2	0

[1]NHEL signifies land not designated as highly erodible; HEL signifies land designated as highly erodible.
Source: Estimated from the 1996 Agricultural Resource Management Survey (ARMS).

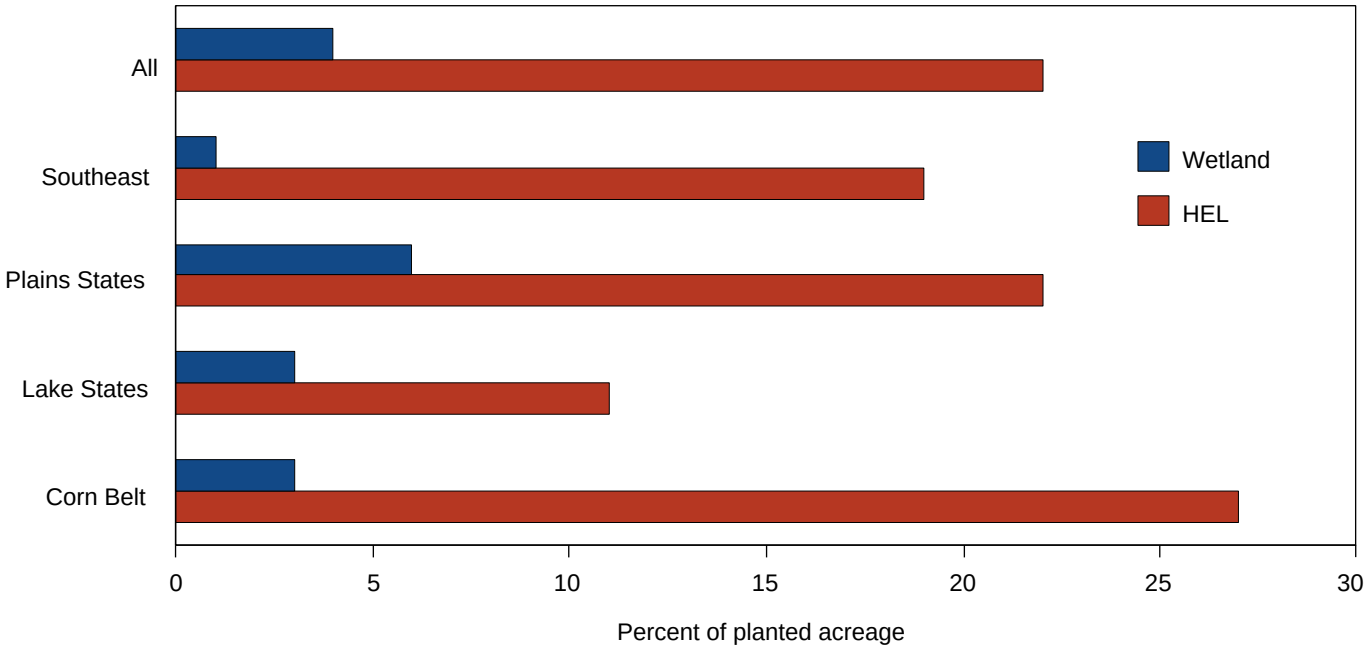
Figure 13
Tillage systems used in corn production on HEL acreage, by region



Farm and Farm Operator Characteristics Associated with Tillage Systems

Several operator and farm characteristics for adopters and nonadopters of different tillage systems are compared in this section (table 5).[2] Age and education were identified as factors that influence tillage adoption in earlier studies. Operators who used a no-till system tended to be younger (47 years, on average) than those who used a conventional tillage system (54 years, on average). While 12 percent of operators using a conventional tillage system had graduated from college, 30 percent of those adopting a no-till system were college graduates. The age of the equipment was not measured, so there was no way to determine if a replacement decision might be influencing the choice of tillage systems.

Figure 14
Highly erodible corn acreage by region
The largest share is in the Corn Belt



The number of acres operated, a variable correlated with several other farm size measures, showed wide variation across tillage systems (table 5). The most notable difference was in the size of the farms: those using a conventional tillage system averaged 460 acres, compared with 718 for farms using reduced-till and 913 acres for farms using no-till systems. Farms using mulch-till systems operated an average of 612 acres. Predictably, gross cash sales, sales class distribution, and acres harvested of specific crops increased with the number of acres operated. Hence, these size indicators also imply that farms using conventional tillage systems tended to be smaller than farms using conservation tillage.

Measures of farm production diversity such as cropping patterns and source of cash receipts differed little by tillage system (table 5). Farms with no-till systems were, on average, less diverse (a large share of acres harvested are corn acres and cash sales are primarily from crops) than those with conventional tillage. Reduced-till farms appeared to be the least diverse, with corn comprising 46 percent of all harvested acreage vs. 35 percent for conventional tillage farms.

Farm finance measures reveal several contrasts between farms adopting no-till systems and those using conventional tillage. Farm size, as reflected in gross cash income and assets, was much smaller for farms using conventional tillage systems than for no-till farms. Furthermore, net farm income was much smaller on the conventional tillage farms ($26,000) than on no-till farms ($67,000) (table 6). Depending on the finance measure, even reduced-till and mulch-till farms tended to be larger and produce higher incomes than conventional tillage farms.

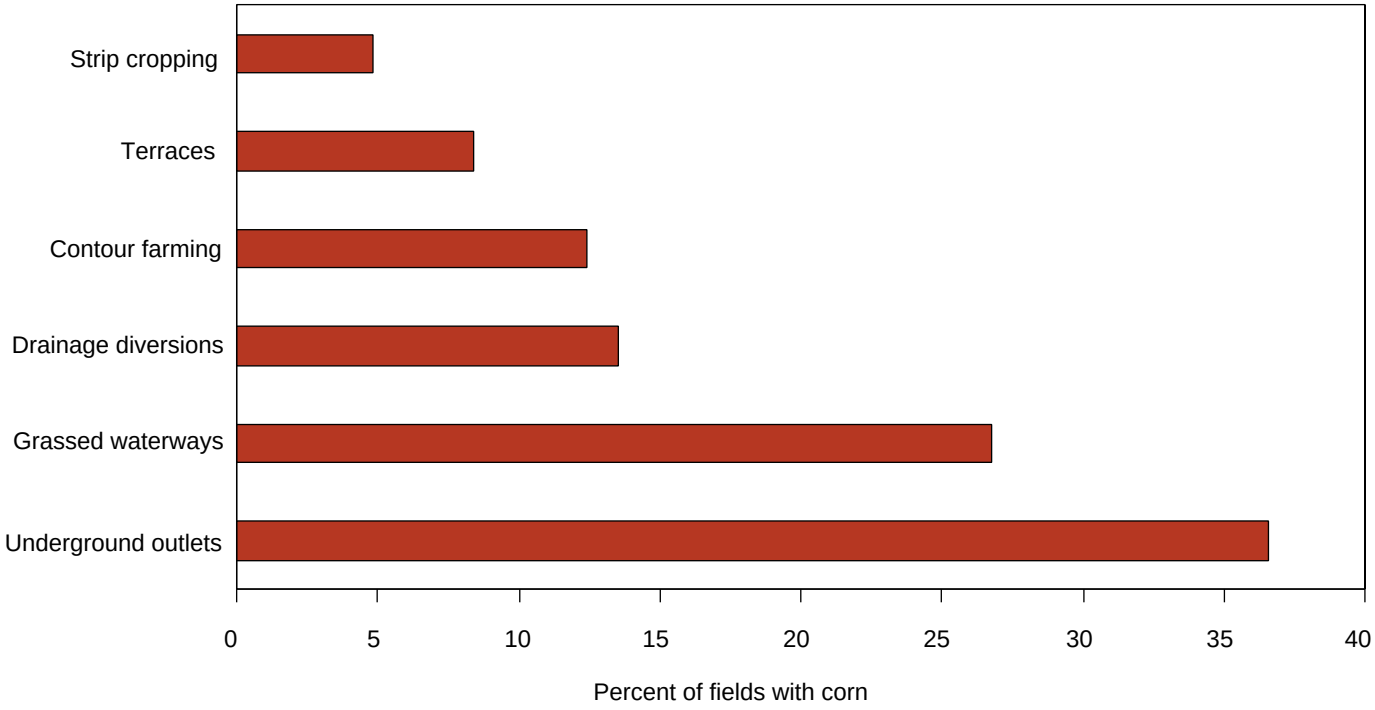
[2]Care must be exercised when comparing the means presented throughout this report. They were obtained from farm survey data and are not the same as those from controlled experiments. Conditions other than the factor being analyzed, e.g., tillage systems or nutrient management practices, are not equal in farm surveys. Thus, differences between mean estimates for operator and farm characteristics from the survey results cannot necessarily be attributed to type of tillage system used. Results are influenced by many other factors, including weather, soils, and nutrient and pest management practices. While one cannot infer causality from the means, they are useful for identifying interrelationships and formulating testable hypotheses for subsequent analysis.

Table 4—Tillage systems used in corn for grain production by soil management structures, 1996

Item	Unit	Grassed waterways	Terraces	Contour farming	Strip cropping	Underground outlets	Drainage channels
Acreage	1,000 acres	20,060	5,053	9,853	2,278	28,590	9,461
Tillage system:	Percent of						
Conventional	acres	21	24	17	38	30	28
Reduced		29	22	35	23	47	44
Mulch-till		23	22	35	26	10	12
No-till		26	25	25	13	12	16
Ridge-till		1	3	3	0	0	0

Source: Estimated from the 1996 Agricultural Resource Management Survey (ARMS).

Figure 15
Adoption rates of conservation practices



The field-level input use data and cost and return enterprise data indicated few consistent differences among farms using different tillage systems. The reduced-till systems tended to have higher gross production values and lower per bushel costs of production than the conventional tillage systems. Yields, with the exception of differences between conventional and reduced-till systems, were fairly consistent across all tillage systems in 1996, which is not surprising given that seed, fertilizer, pesticide, and manure use per acre were similar for most tillage categories (table 6) (figs. 16 and 17).

Table 5—Operator and farm characteristics of corn producers by tillage system, 1996

Item	Unit	Tillage system				
		Conventional	Reduced	Mulch	No-till	All
Operator characteristics:				Average		
Age	Years	54	51	51	47	52
Education:	Percent of farms					
H.S. or less		67	58	56	41	60
Some college		21	28	32	29	26
College grad.		12	14	12	30	15
Farm characteristics:				Average		
Size:	Acres					
Acres operated		460	718	644	913	612
Acres harvested						
Corn		115	263	183	275	182
Soybeans		81	219	120	205	136
Wheat		31	30	40	66	37
Other		103	58	114	105	95
Gross cash sales:	$1,000 per farm					
Livestock		46	57	79	61	56
Crops		56	119	94	128	86
Gov. Pmts.		5	8	6	9	6
Other		12	16	17	14	14
Sales class:	Percent of farms					
$0-$99,999		64	39	34	36	50
$100,000 to $249,999		24	33	47	34	31
$250,000 to $499,999		8	22	9	20	13
$500,000+		4	7	10	9	6
Acres harvested:	Percent of acres					
Corn		35	46	40	42	40
Soybeans		25	38	26	31	30
Wheat		9	5	9	10	8
Other		31	10	25	16	21
Gross cash receipts:	Percent of receipts					
Livestock		39	29	40	2	34
Crops		48	59	48	61	53
Gov. Pmts.		4	4	3	4	4
Other		10	8	9	6	9

Note: Percents may not add to 100 due to rounding.
Source: Estimated from the 1996 Agricultural Resource Management Survey (ARMS).

Table 6—Farm finances corn yields, and costs and returns, by tillage system, 1996

Item	Unit	Tillage system				
		Conventional	Reduced	Mulch	No-till	All
Farm finances:	$1,000 per farm					
Income statement						
Gross cash income		118	200	196	211	162
Var. cash expenses		68	105	112	112	90
Fixed cash expenses		22	40	31	40	30
Net cash income		29	55	52	60	43
Net farm income		26	57	50	67	42
Balance sheet:	$1,000 per farm					
Assets		520	847	844	798	686
Liabilities		74	144	102	142	104
Equity		447	703	741	656	582
Debt-to-assets ratio	Percent	0.14	0.17	0.12	0.18	0.15
Return on equity	Percent	5.74	8.08	6.72	10.19	7.28
Corn enterprise:						
Yields	Bushels per acre					
Actual		117	140	125	125	128
Normal		132	140	131	130	134
Costs and returns:	Dollars per					
Gross value of prod.	planted acre	335	394	359	357	363
Total cash expenses		207	216	222	203	212
Land cost		73	94	86	92	86
GVOP less cash exp.		128	178	136	154	151
Unit costs—	Dollars					
Var. cash exp.	per bushel	1.33	1.16	1.38	1.19	1.25
Total cash exp.		1.76	1.54	1.78	1.62	1.66
Seed	1,000 per acre	27.0	27.7	27.4	26.2	27.2
Fertilizer:	Lbs. per treated acre					
Nitrogen		129	147	124	128	134
Phosphorus		50	58	43	61	54
Potassium		80	79	62	66	74
Pesticides:	Lbs. per treated acre					
Herbicides	(active ingredients)	2.55	2.70	2.27	3.00	2.64
Insecticides		0.74	0.70	0.59	0.71	0.69
Manure	Tons per treated acre	8.32	4.90	3.68	8.22	6.02
Irrigation	1,000 acres	2,680	2,420	2,600	2,060	9,760
	Percent of acres	13	11	21	15	14

Source: Estimated from the 1996 Agricultural Resource Management Survey (ARMS).

Figure 16
Input use by tillage practice

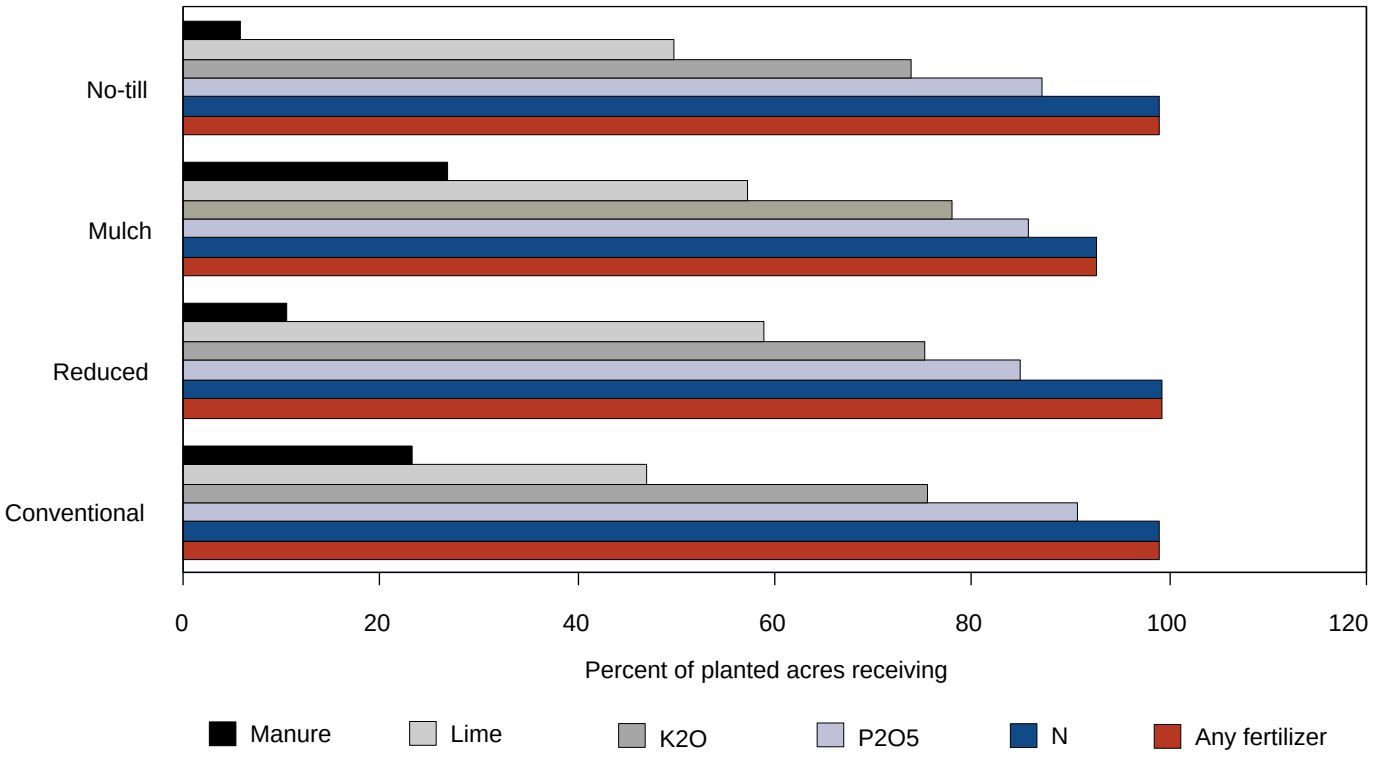
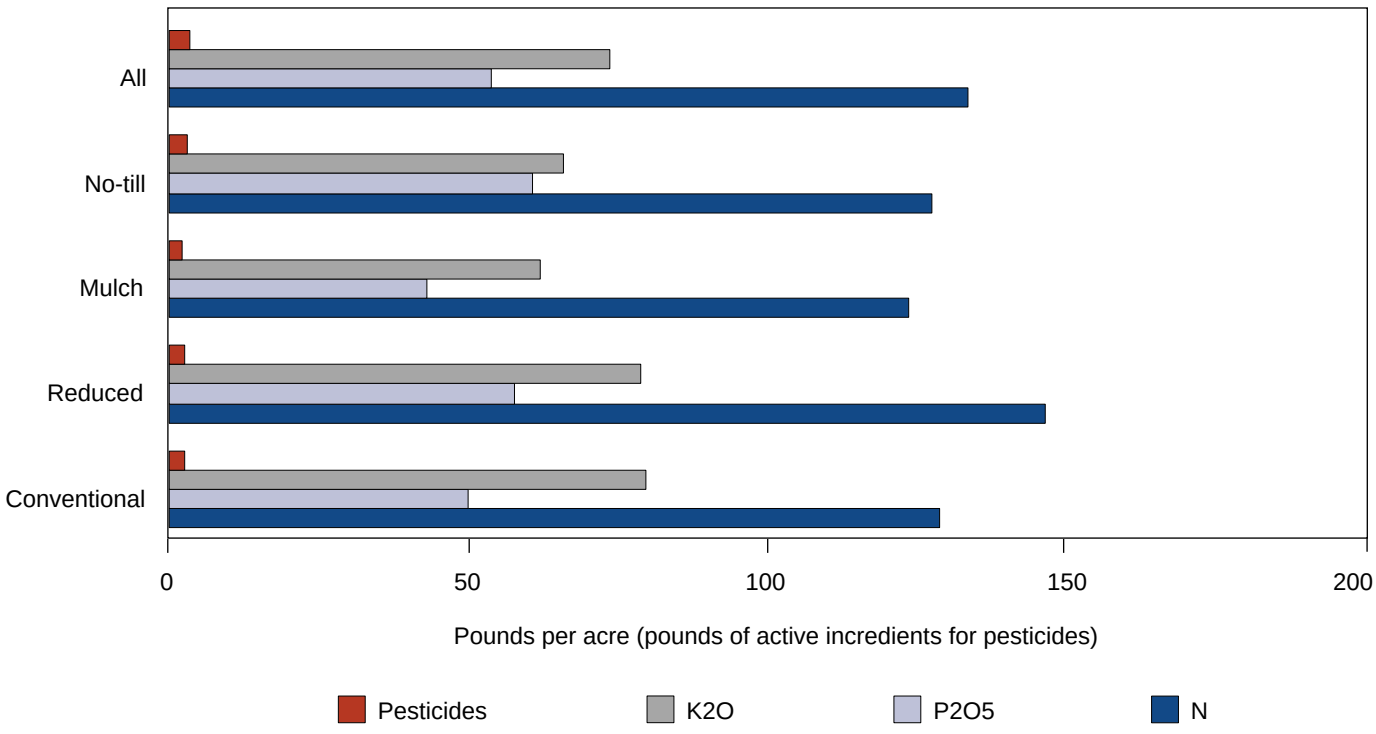


Figure 17
Fertilizer and pesticide use in corn production by tillage practice



Nutrient Management Systems in Corn Production

Nutrient management in corn production has an impact on soil fertility, yields, profitability, and environmental risk. Soil fertility involves the complex interactions between the biological, chemical, and physical properties of the soil. Physical properties encompass such factors as soil density, waterholding capacity, and rooting depth, all of which can affect both plant growth and nutrient leaching and runoff. Chemical properties include soil pH, nitrogen, phosphorus, potash, and sulfur status and organic matter content. Of the factors affecting soil fertility, many are rarely in equilibrium and change from year to year. These dynamics create the need to periodically monitor soil nutrient levels and assess the need for fertilizer and soil amendments. Commercial or organic fertilizers enhance the soil content of nitrogen, phosphorus, and potash, critical nutrients for corn production. If these nutrients were not applied, the soil's store of nutrients would become depleted and current yields could not be sustained in most corn-growing areas.

A number of nutrient management tools are available to corn producers to improve economic performance and reduce the availability of residuals that may pollute the environment (Ferguson et al., 1994). In U.S. corn production, the recommended or best management practices typically include a number of actions, done individually or combined with others. Some of these tools are identified in the box "Examples of Nutrient Management Tools."

Agronomists typically advise farmers to use these recommended practices in sequence, beginning with the establishment of a yield goal, as a precursor to estimating the total amount of nutrients needed by the crop. However, several approaches can be used in the first step, formulation of yield goals. If a goal of profit maximization is assumed, the optimal input use and yield goal will be determined jointly, taking into account price and cost relationships. In contrast, yield goals set by agronomists typically reflect average or normal yields for the field, considering only agronomic response relationships. The amount of commercial fertilizer is typically determined after credit is given to the amount of nutrients available from the soil, the previous legume crop, and livestock manure. Once the needed amount of fertilizer is estimated, management decisions can be made about the fertilizer application method and timing, as well as whether to use more sophisticated technologies such as nitrogen inhibitors or variable-rate fertilizer application. Variable-rate application is a precision agriculture tool that can be used to vary fertilizer application rates within a field, with a goal of tailoring total fertilizer applications to reflect the variability of soil conditions within a field.

Sources of Nutrients Used in Corn Production

Most corn producers fertilize, using a variety of sources. The share of acreage on which nutrients are used varies among the major farm production regions (table 7). Commercial nitrogen was applied to 98 percent of the corn acreage and commercial phosphate to 87 percent (fig. 18). The use of both manure and commercial fertilizer was reported on 15 percent of the acreage nationally but on 29 percent of the Lake States acreage, reflecting the relatively intense livestock industry, particularly dairying, in that area. Only 14 percent of the Corn Belt acreage received manure, followed by 10 percent of the Southeast and 6 percent of the Plain States. Table 7 also shows the 1996 commercial fertilizer application rates on corn acreage. Nationally, commercial fertilizer is the major source of nutrients, providing an average of 83 percent of all the nitrogen available per treated acre, 91 percent of all the phosphorus, and 88 percent of all the potassium. Legumes contributed an average of 13 percent of the total nitrogen available, and manure an estimated 4 percent. In the Lake States, however, manure accounted for an estimated 10 percent of the available nitrogen.

Use of Selected Nutrient Management Practices

Survey results indicate that the use of nutrient testing techniques in corn production varies widely among regions. Forty-three percent of planted corn acreage received a soil or plant tissue test, but only 21 percent received a nitrogen test. However, nitrogen management on the acres receiving the nitrogen test followed recommendations closely, with 82 percent of the acres receiving nitrogen at exactly the rates recommended or lower (table 8). In the Plains States, nearly half of the corn acres were tested for nitrogen, and on 84 percent of the tested acres, nitrogen was applied at rates matching or below the test recommendations. These application rates probably reflect the rigorous nitrogen monitoring process in Nebraska, one of the major corn-producing States in the Plains area. In the

Examples of Nutrient Management Tools

- Formulation of realistic yield goals
- Soil or tissue testing to assess the need for additional fertilizer
- Selection of appropriate fertilizer products
- Adjustment of fertilizer application rates to account for the nitrogen available from previously planted legumes
- Adjustment of fertilizer application rates to account for nutrients contributed by manure applied to fields
- Application of nitrogen in irrigation water
- Incorporating fertilizer into the soil during or soon after application to minimize surface runoff or volatilization of nutrients.
- Timing fertilizer applications to minimize potential losses to the environment; for example, applying all nitrogen at or after planting, when the demand by the crop for nutrients is greatest, to reduce the risk of nitrogen loss through leaching. Applying all nitrogen in the fall may increase the risk of leaching.
- Using nitrification inhibitors where necessary to slow the release of nitrates from ammonium fertilizers until later in the growing season, in order to reduce nitrate leaching by delaying the conversion of ammonium into nitrate.
- Using precision agriculture technologies to increase the efficiency of each unit of fertilizer, lime, and pesticide applied, thereby reducing negative environmental residuals.

(Adapted from Ferguson et al., 1994)

Southeast, by contrast, only 13 percent of the acres were tested for nitrogen, and only 40 percent of the tested acreage followed the recommendations or applied less nitrogen than recommended (table 8 and figs. 19 and 20).

The timing and method of nitrogen fertilizer application and incorporation varies by region, as is shown in table 8. Broadcast application with incorporation was used on 15 percent of the acreage. Methods other than broadcasting were used on 40 percent of the acreage. Over 40 percent of the corn acres had some nitrogen applied by broadcasting, but without incorporation (table 8). Nitrogen fertilizer was applied before planting, either in the fall, the spring, or both, on 42 percent of the total acreage. All the nitrogen was applied in the fall to 13 percent of total acreage, but to almost 20 percent of the acreage in the Corn Belt. Thirty percent of all corn acreage received 100 percent of the nitrogen at or after planting, but this ranged from 45 percent in the Lake States to 24 percent in the Corn Belt. Nitrogen inhibitors were used on 9 percent of the national acreage, mostly in the Corn Belt (table 8).

Manure was applied to almost 40 percent of the acreage in the Lake States, a region with relatively intense livestock production. In other areas, manure was applied to 4 to12 percent of the acreage, with the lowest application in the Plains States (table 8 and fig. 21). Manure incorporation into the soil following application was reported on 7 percent of the acreage, and application without incorporation on 10 percent. In the Lake States, 25 percent of the acres received manure without incorporation and 12 percent with incorporation (fig. 21).

Precision agriculture technologies, such as grid sampling, variable rate fertilizer application, and yield monitors, are primarily used for more intensive subfield management of commercial fertilizer. Precision agricultural technology applications in corn production

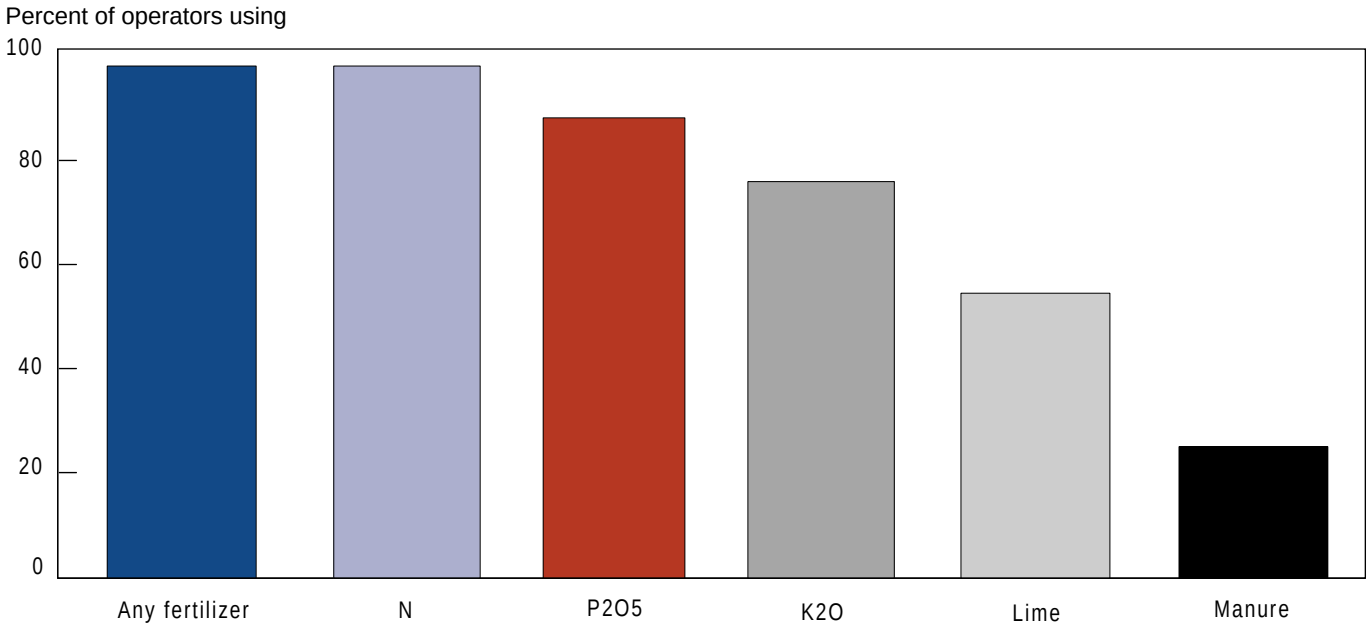
Table 7—Characteristics of farms producing corn, nutrient sources, and fertilizer application rate, by region[1]

Item	Corn Belt	Lake States	Plains States	Southeast	All
Number of farms raising corn (1,000)	163	111	63	26	363
Acres in corn (1,000)	35,571	14,390	16,153	2,672	68,786
Farm size:					
Operated acres	578	403	1,103	467	612
Owned acres	224	236	468	209	269
Cash rented acres	165	153	330	175	191
Share rented acres	199	18	314	79	155
Acres harvested:					
Corn for grain	209	120	257	96	182
Soybeans	206	68	88	94	136
Wheat	23	16	109	43	37
Other crops	46	107	163	185	95
Total	484	311	616	419	449
			Bushels per planted acre		
Yields:					
Actual	138	127	125	113	128
Normal	139	129	131	117	134
Source of nutrients:			*Percent of planted acres*		
Commercial fertilizer—					
Nitrogen	100	94	98	99	98
Phosphorus	89	90	80	95	87
Potassium	87	84	43	95	76
Manure	14	29	6	10	15
Manure and commercial fertilizer	14	29	6	10	15
Cropping pattern:					
Continuous corn	11	15	44	5	19
Corn-legumes	82	53	30	80	64
Other	6	32	27	15	16
			Lbs. applied per treated acre		
Commercial fertilizer:					
Nitrogen	145	111	142	135	137
Phosphorus	63	53	34	71	55
Potash	87	68	26	87	75
Lime (tons)	2.3	2.2	1.3	1.5	2.2

[1]Regional designations are: Corn Belt—IL, IA, IN, OH, MO; Lake States—MI, MN, WI, PA; Plains States—NE, KS, SD, TX; and Southeast—KY, NC, and SC.

Source: Estimated from the 1996 Agricultural Resource Management Survey (ARMS).

Figure 18
Fertilizer use, by type
Most corn producers fertilize



have become more common since the mid-1990s. In 1996, some form of precision agriculture technology was used on 23 percent of the total corn acreage, with a range of 19 to 26 percent among the regions. The Corn Belt had the highest precision technology use, which reflects an early emphasis by the developers of the technology on its application to corn production. As these technologies are relatively new, 1996 was the first time information was collected for them in the ARMS survey.

Interrelationships of Nutrient and Tillage Management

ARMS survey results highlighted how tillage systems also seemed to influence nutrient management practices. Soil or tissue tests were used most often on acreage using no-till or mulch-till systems and least often on conventionally tilled acreage. Few differences were noted in the use of nitrogen inhibitors, with a range of 6 to 11 percent among the various tillage systems (table 9 and fig. 22).

A greater share of acres in no-till than in conventional tillage received nitrogen in the fall prior to planting, with a smaller percentage in the spring at or before planting. The broadest spectrum of methods used for all fertilizer was on conventionally tilled acreage. Broadcast and injection application was used on a larger share of no-till acreage than on conventionally tilled acreage, 74 percent compared with 67 percent for broadcast and 60 percent compared with 50 percent for injection (figs. 23, 24, and 25).

Analysis of the crop residue management systems and types of fertilizer applied or application rates found few differences among various tillage systems, except for manure application, where a much smaller share of no-till acres received manure than did conventional acreage. This is understandable given the need to incorporate manure following application, for both environmental and economic reasons (fig. 26).

Table 8—Regional comparisons of nutrient management systems used in corn production, by region[1]

Nutrient management	Corn Belt	Lake States	Plains States	Southeast	All
			Percent of planted acres		
Testing:					
Soil or tissue test	40	36	52	58	43
Nitrogen test	15	11	46	13	21
Based on N test applied:					
More than recommended	22	5	15	60	18
Less than recommended	14	21	14	1	14
Exactly recommended	64	74	70	39	68
Nitrogen inhibitors	14	3	5	2	9
Nitrogen application timing:					
All in fall	19	5	6	0	13
None at/after planting	32	14	33	28	28
Less than 50% at/after planting	9	21	19	11	14
50-99% at/after planting	15	7	12	22	13
All at/after planting	24	45	27	38	30
Nitrogen application method:					
None broadcast	40	45	42	7	40
Broadcast with incorporation	14	18	15	17	15
<100% broadcast w/o incorporation	31	21	24	46	28
All broadcast w/o incorporation	15	9	16	29	14
Manure application:					
None	86	62	93	90	83
Without incorporation	7	25	3	9	10
With incorporation	7	12	3	1	7
Nitrogen balance:					
Negative	12	37	28	17	21
0-25 pounds per acre	14	10	31	4	16
Exceeds 25 pounds per acre	75	54	41	80	62
Precision agriculture technologies	26	19	23	22	23
Cropping pattern:					
Continuous corn	11	14	43	5	19
Corn-legumes	83	49	30	80	63
Other	6	37	27	15	18

[1]Regional designations are: Corn Belt—IL, IA, IN, OH, MO; Lake States—MI, MN, WI, PA; Plains States—NE, KS, SD, TX; and Southeast—KY, NC, and SC.

Source: Estimated from the 1996 Agricultural Resource Management Survey (ARMS).

Figure 19

Use of nutrient management tools by percent of farms and region

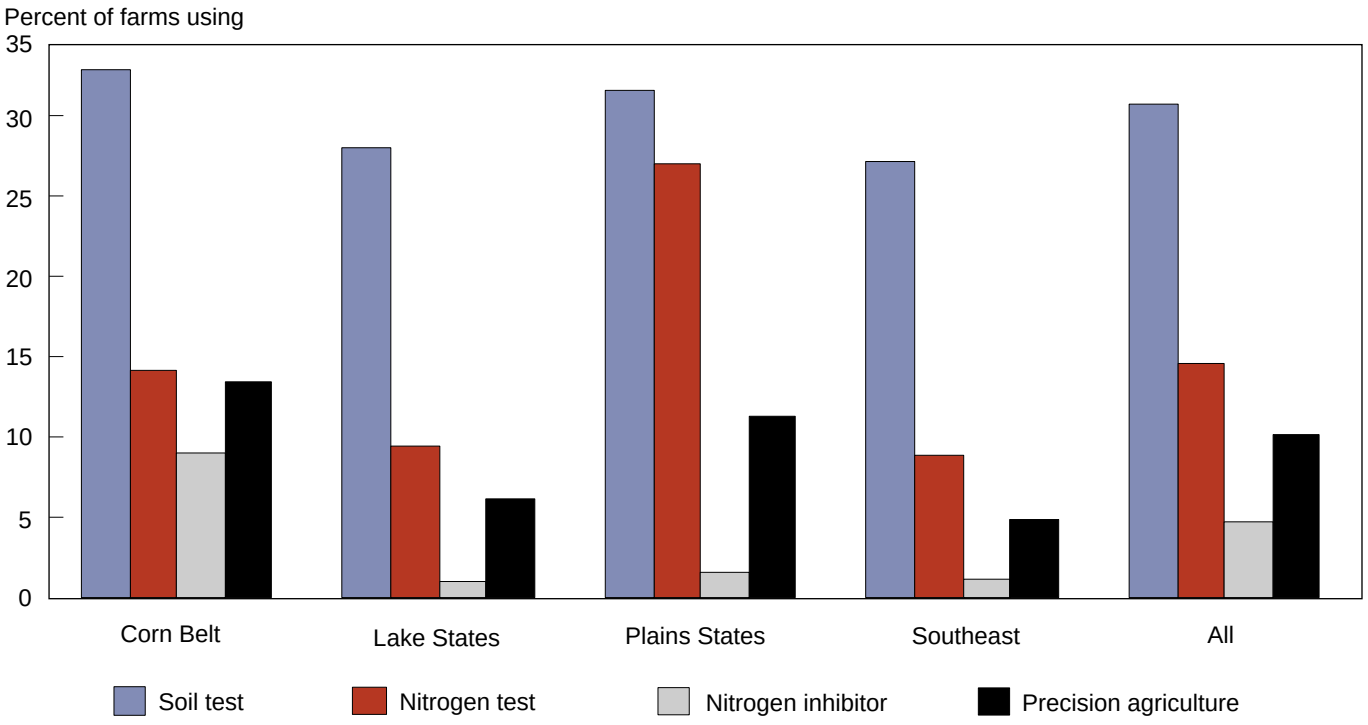


Figure 20

Use of nutrient management tools by acreage and region

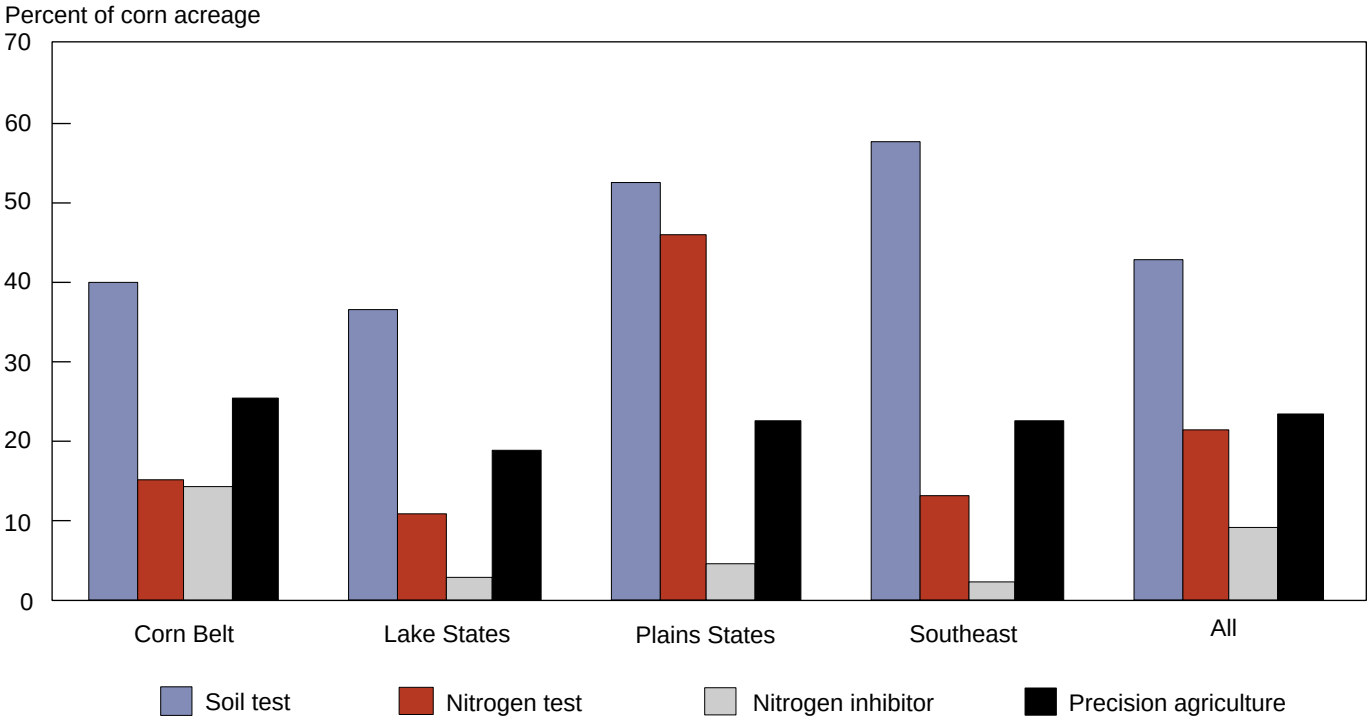


Figure 21

Corn acreage receiving fertilizers, by region

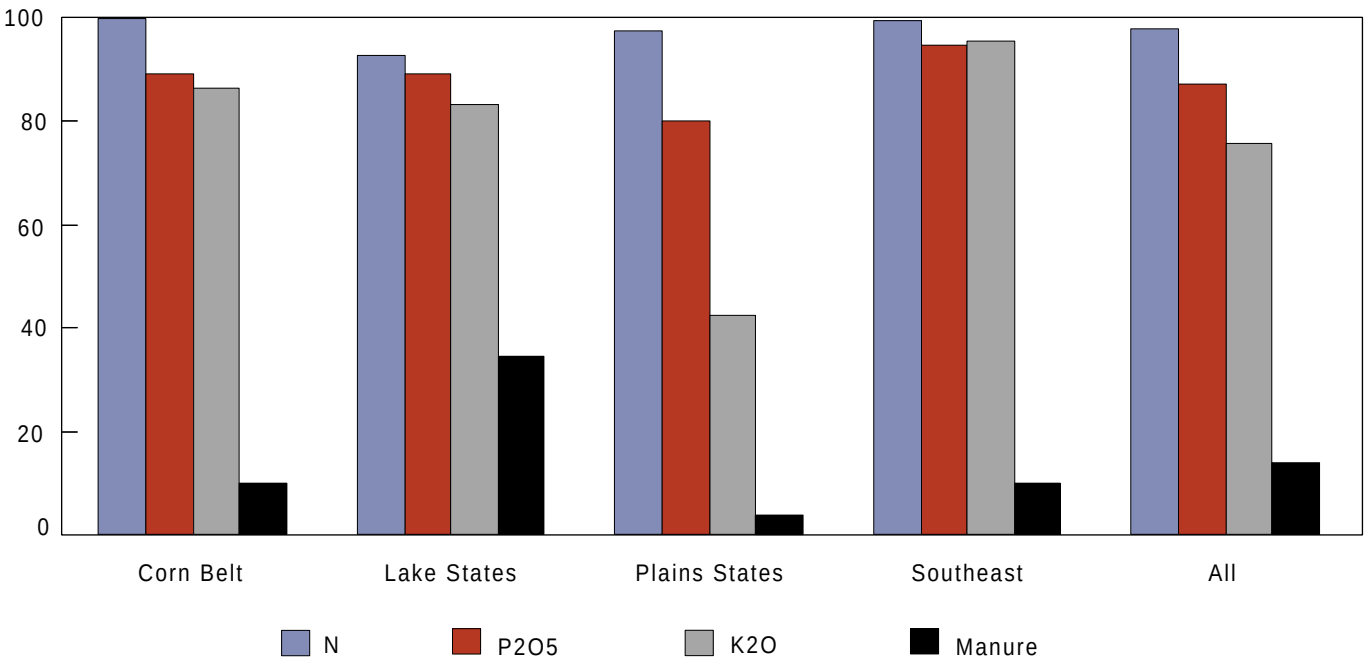


Table 9—Comparisons of nutrient management systems used in corn production by tillage practice, 1996

Nutrient management	Conventional tillage	Reduced tillage	Mulch tillage	No-till	All
			Percent of planted acres		
Testing:					
Soil or tissue test	38	41	43	55	43
Nitrogen test (% tested acres)	59	49	58	38	50
Based on N test applied:					
More than recommended	18	15	11	28	18
Less than recommended	14	13	22	8	14
As recommended	68	72	67	64	68
Nitrogen inhibitors	8	11	6	11	9
			Percent of treated acres		
Nitrogen application timing:					
Fall, before planting	19	34	3	30	23
Spring, before planting	48	53	64	41	51
At planting	49	32	56	39	42
After planting	32	31	40	37	34
Fertilizer application method:					
Broadcast to ground	67	76	71	74	72
Broadcast to air	2.9				0.9
Chemigation	1.6	1.4	13		3.2
Banded	42	32	49	34	39
Foliar	2.2	1.6	6.8	1.4	2.6
Injected (knifed)	50	57	57	60	56
			Percent of acres receiving		
Acres receiving:					
Any commercial fertilizer	99	99	93	99	98
Commercial nitrogen	99	99	93	99	98
Commercial phosphorus	91	85	86	87	87
Commercial potassium	76	75	78	74	76
Lime	47	59	57	50	53
Manure	23	10	27	6	16
Manure and commercial fertilizer	22	10	20	6	15
			Pounds per treated acre		
Average application rates:					
Commercial nitrogen	133	150	128	131	137
Commercial phosphorus	52	59	44	65	55
Commercial potassium	81	80	61	67	75
Lime (tons)	2.3	2.3	2.1	2.0	2.2
Precision agriculture technologies:					23
Cropping pattern					
Continuous corn					19
Corn-legumes					63
Other					18

Source: Estimated from the 1996 Agricultural Resource Management Survey (ARMS).

Figure 22

Nutrient management tools by tillage type

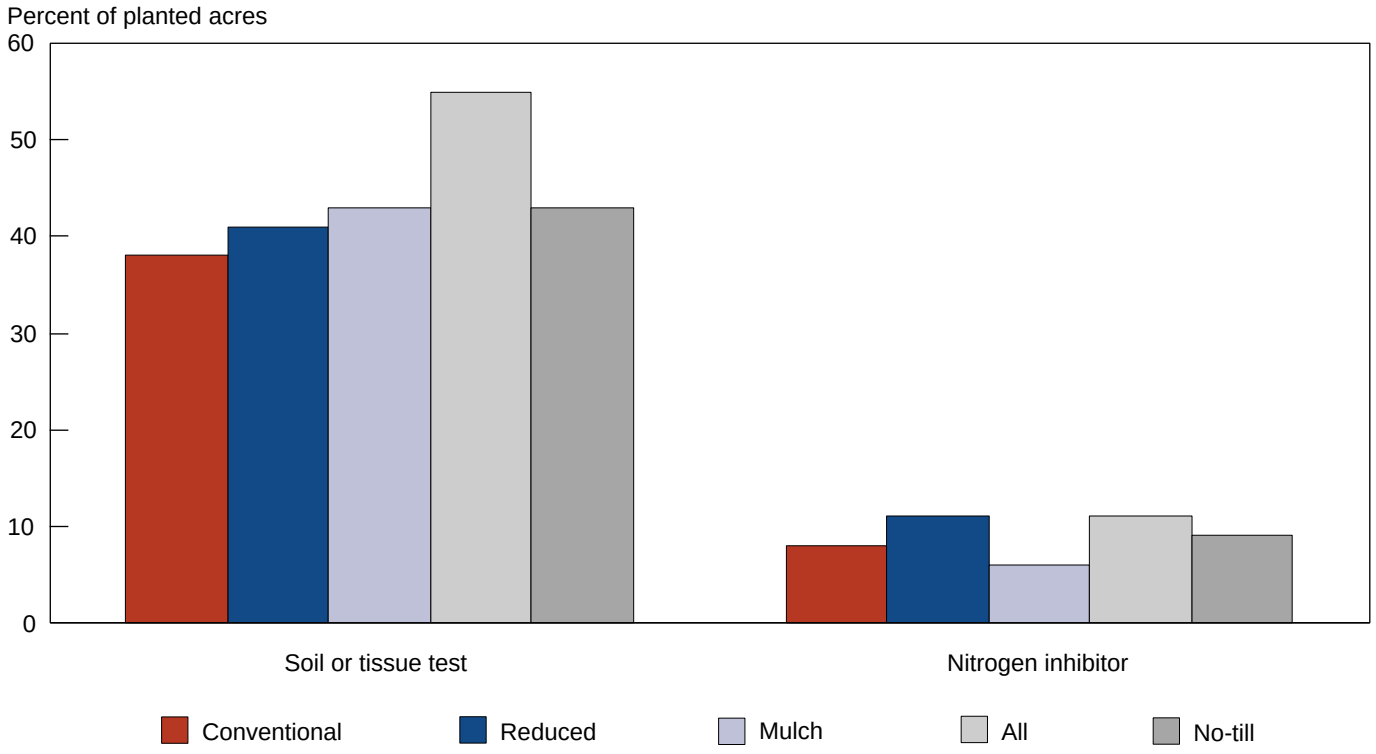


Figure 23

Nitrogen fertilization timing by tillage type

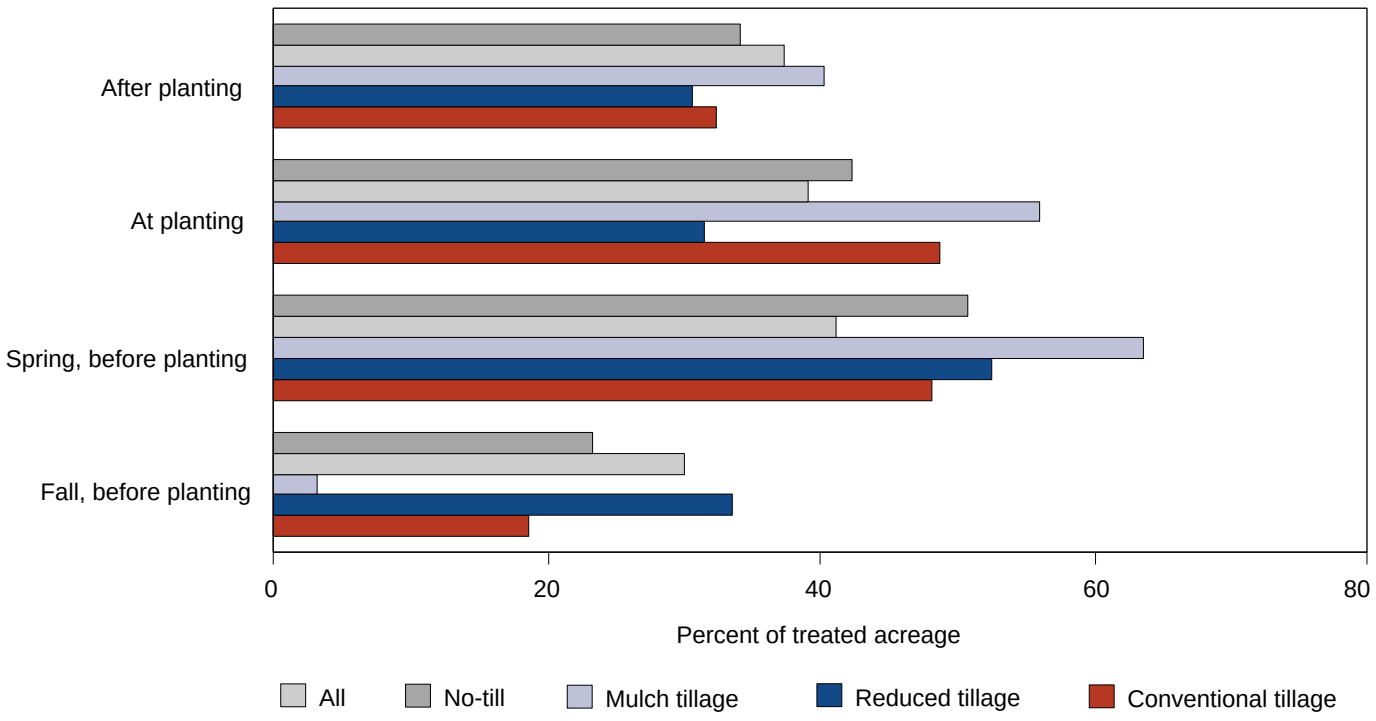


Figure 24

Fertilizer application by tillage system

Broadcasting and injection are the most frequent

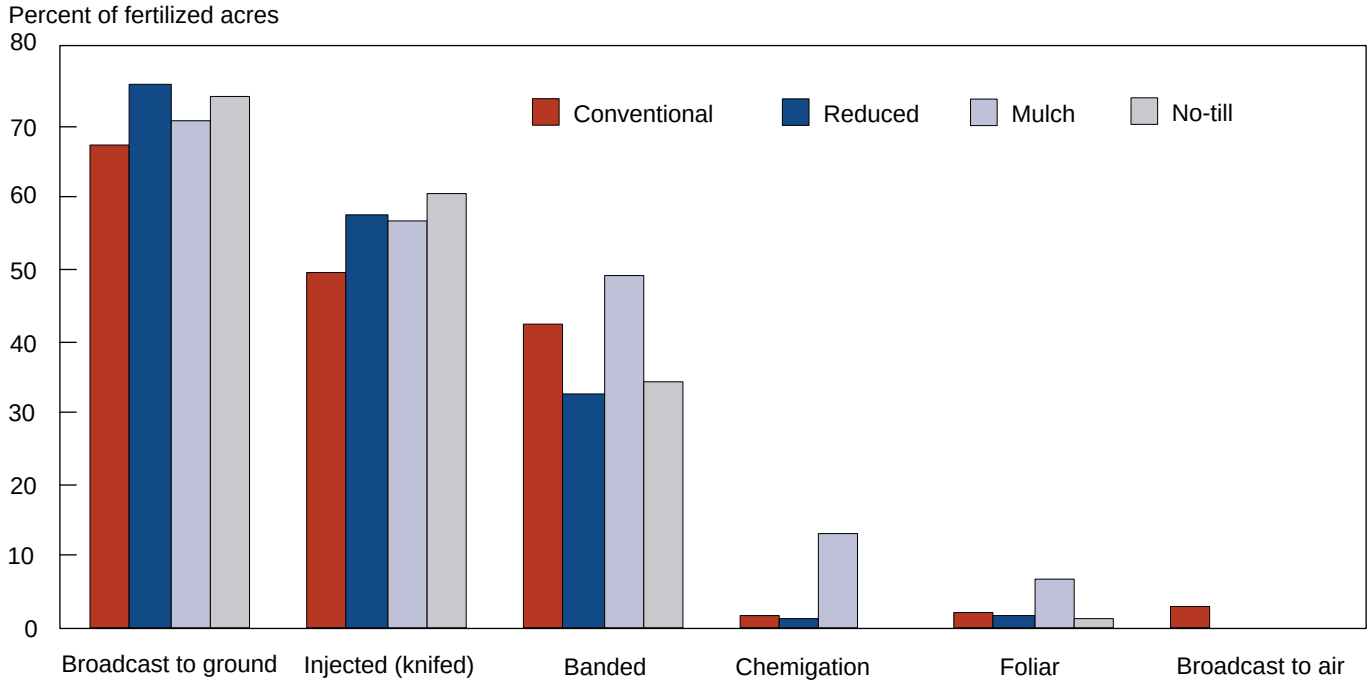


Figure 25

Nitrogen fertilization rate by tillage type and method of application

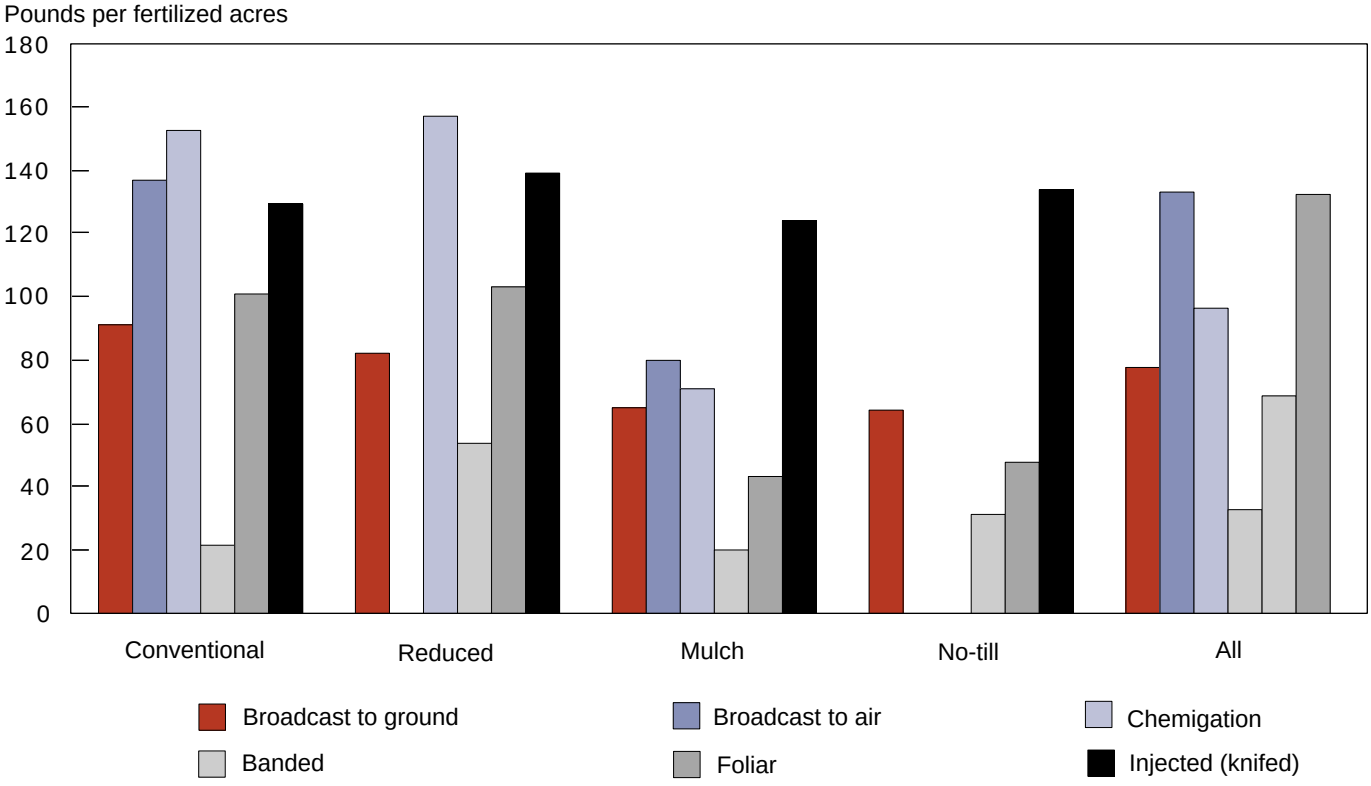
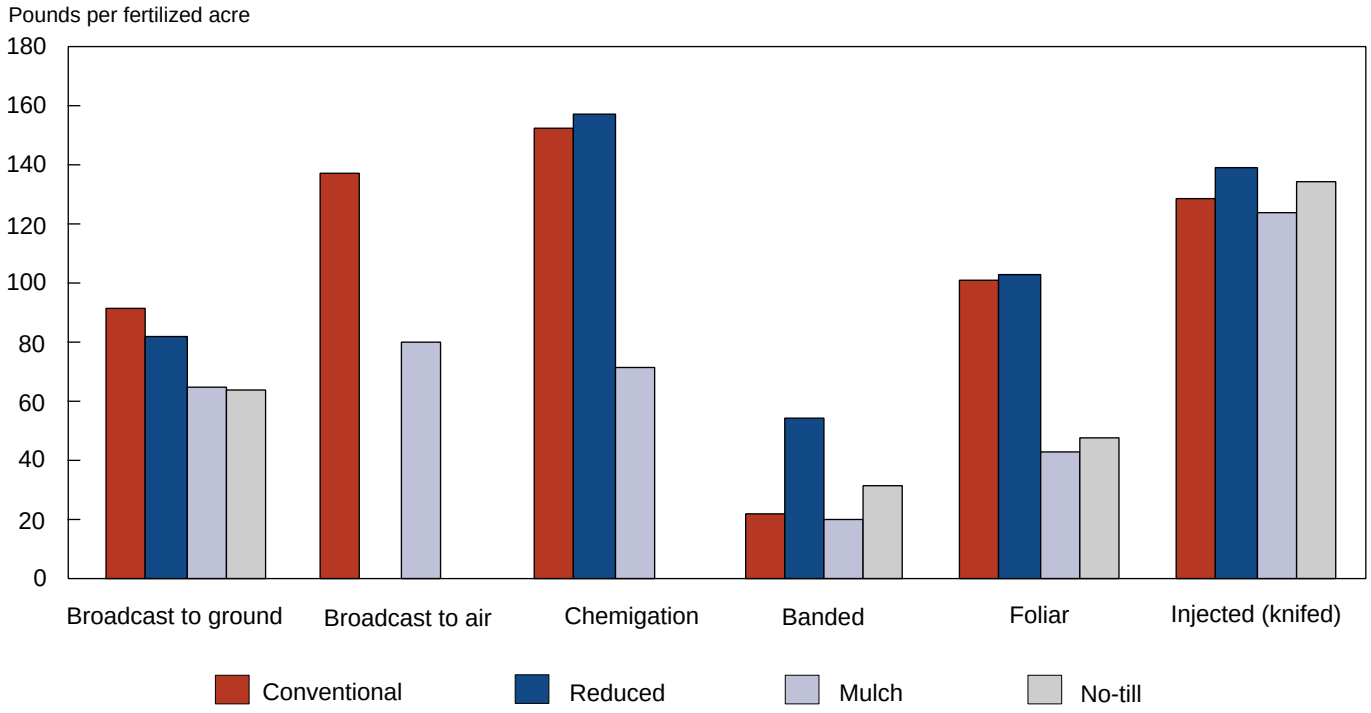


Figure 26

Average nitrogen fertilization rate by application method and tillage type



Irrigation Management Systems in Corn Production

Corn for grain has substantially more irrigated area than any other single crop in the United States. According to the most recent census of agriculture, 10.6 million acres of irrigated corn were harvested in 1997, 15 percent of the total corn acreage (USDA, 1999a). Irrigated corn was produced on 9 percent of the farms harvesting corn for grain and represented about 19 percent of total grain corn production. Nationwide, irrigated corn yields were about 29 percent higher than nonirrigated yields. In addition to increasing yield, irrigation expands production into areas normally too arid for corn production, as evidenced by the fact that 9 million (85 percent) of the irrigated corn acres were in the 19 Western States.[3] While the 31 Eastern States irrigate only 3 percent of the total corn area, Western States irrigate 50 percent. Most of the nonirrigated area in the Western States is in the eastern half of the Plains States, where climate is more similar to that of Eastern States. Nebraska had 47 percent of the irrigated corn acreage in 1997. The other major States producing irrigated corn are Kansas, Texas, and Colorado, with 14, 8, and 7 percent of the irrigated corn acreage, respectively, in 1997.

Irrigated corn producers make choices that result in more or less efficient use of water. These producers, like other irrigators in the Nation, face increasing competition for tightening water supplies. Irrigators have responded by reducing water losses, increasing yields, and becoming more efficient in the use of all inputs. More output per inch of water input may be achieved by producing higher yields with the same water application, by maintaining yields with reduced water applications, or by achieving some combination of higher yields and less water.

One mechanism to increase water available for plant growth relative to the quantity of water taken from streams or aquifers is by reducing water losses, in other words, by increasing the irrigation efficiency of the delivery system. Negri and Hanchar (1989) provide ranges of irrigation efficiencies for different water delivery technologies. In general, sprinkler technologies can be more efficient than gravity irrigation and provide more uniform water application, which can reduce nitrate leaching. In addition to the potential for water conservation and higher yields, sprinklers may also use less labor and have potential as a nutrient and pesticide delivery system. However, substituting sprinklers for gravity systems can be expensive from both a fixed cost (initial system expense) and a variable cost (pumping expense) perspective.

Improving the irrigation delivery system is one way to use water more effectively. Better management through proper timing of water applications and applying the optimal water depth for a given field, crop, growth stage, and climate may greatly improve the efficiency of an existing system. Adding a delivery system capable of greater water control—a sprinkler system, for instance—may enable such improvements in irrigation management.

Irrigation Management Systems

Irrigation management systems generally incorporate a variety of irrigation technologies and water management practices. Previous studies of the adoption of water-conserving systems have examined either a technology or a management practice independently. However, irrigation systems are combinations of application technology, management practices, and information. The data available in the ARMS enable simultaneous consideration of these components to develop more inclusive measures of irrigation management systems.

Many technologies are available for irrigating corn, ranging along a spectrum of capital and labor intensiveness/extensiveness. They also differ according to irrigation water conservation potential and management requirements. Irrigation technologies can be grouped into several categories, according to their potential for increasing water conservation: gravity, basic sprinkler, improved sprinkler, and “other” technologies. Details on the technologies in each of these categories are given in appendix B.

For irrigated corn producers, several water management techniques are available to help with decisions about irrigation scheduling and water conservation. A producer may use one or more of these, including: (1) scheduling irrigation with commercial services or computer simulation models, (2) scheduling irrigation

[3]The 19 Western States are the 17 States to the west of, and including, the Plains States from North Dakota to Texas, plus Alaska and Hawaii.

with on-farm techniques such as soil-moisture sensing devices, and (3) on-farm use of special furrowing techniques to control water distribution and reduce water loss.

Numerous sources of information are available to help establish the efficient scheduling of irrigation water and are important in making water management decisions. These sources include: (1) irrigation equipment dealers or neighboring farmers, (2) extension agents and university and government specialists, (3) off-farm electronic information and media reports of area water use, and (4) commercial scheduling services or local water district specialists.

Prevalence of Irrigation Management Systems on Corn Acreage

The ARMS asked producers to identify, in addition to their application technology, the management practices they use and their sources of information. For this analysis, the components of farm irrigation management systems were combined in keeping with common understanding about how choices among application systems, management practices, and information sources are likely to affect irrigation efficiency.

The sampling and editing procedure used for the ARMS resulted in only 64 usable irrigated corn farm responses, all from the Plains States of Nebraska, Kansas, and Texas. While the geographic coverage is limited to these three States, they account for almost 70 percent of the corn area under irrigation nationally. Nebraska alone accounts for 47 percent of this area (USDA, 1999a). The small sample size limits the ability to draw strong inferences from the data. Of the corn acreage irrigated, 42 percent was by gravity flow systems, 19 percent by basic sprinkler technologies (for example, big gun and center pivots with sprinklers on the main pipe), and 39 percent by advanced sprinkler technology (such as center-pivot and linear-move tower sprinklers with sprinklers below the main pipe) (table 10).

Irrigation technology use was mixed, with some farms having most of their irrigated acreage under improved sprinkler technologies but also using gravity systems. The use of irrigation management practices varied considerably. The practices requiring the most intensive management include on-farm, special furrowing techniques to control water distribution and reduce water loss. Another intensive management tool is to schedule irrigation using off-farm services (commercial services or computer simulation models).

Survey respondents were asked to choose their top three sources of irrigation information. The source described as "information provided by local irrigation district personnel or specialists hired by the local water district" was used by 43 percent of all farms. Private irrigation specialists served only 5 percent of farms. Many farmers relied on local information sources. Neighboring farmers were an information source for 31 percent of corn producers and irrigation equipment dealers for about 24 percent. Extension agents provided irrigation information to about 19 percent of the irrigators and specialists from other government agencies to about 10 percent. Computer-based information sources, including the Internet, were a resource for about 19 percent of producers. But information from these sources is generally developed by the Extension Service or other government agencies (county, State, and Federal) (table 10). Local irrigation district personnel or specialists hired by the local water district provided information for producers farming about two-thirds of the irrigated corn area.[4]

Thus, irrigated corn producers have many sources of information to help them in their decisionmaking. More analysis is needed to assess whether these resources provide information of the quality and credibility to make it useful to producers in their individual locales.

[4]The strong role of irrigation district personnel or specialists hired by the local water district as information sources is not representative of the Nation's, or the West's, irrigated area. Over three-quarters of the usable surveys are from Nebraska farms. Nebraska has a strong, well-supported, statewide local water district system. Results from a 1998 survey (USDA, 1999b) indicate about 20 percent of the West's irrigators rely on local irrigation districts as an information source.

Table 10—Yields, irrigation system attributes, and irrigation information uses by irrigated corn producers, Plains States

Item	Units	Total
Irrigated corn yield	Bushels per acre	154
Gross value of sales	$1,000 farm	381
Water supply:		
Water sources (corn)		
Groundwater only	Percent of acres irrigated	88
Surface water or combined sources	Percent of acres irrigated	12
Well information (farm):		
Average per farm	Number	5.5
Wells with--		
Backflow prevention devices	Percent of wells	64
Water flow meters	Percent of wells	22
Ground-water irrigated acres with		
Backflow prevention devices	Percent of acres	71
Water flow meters	Percent of acres	23
Water management:		
Water applied	Inches	10.5
Water application method:		
Gravity	Percent of acres	42
Basic sprinkler	Percent of acres	19
Improved sprinkler	Percent of acres	39
Water decision information (farm):		
Cultivation methods to reduce water loss	Percent of acres irrigated	13
On-farm, e.g., moisture sensing devices	Percent of acres irrigated	6
Off-farm, e.g., scheduling service	Percent of acres irrigated	11
Water information sources (farm):	Percent of farms selecting source	
Local irrigation district	in top 3 choices	43
Neighboring farms		31
Irrigation equipment dealers		24
University specialists and cooperative extension service agents		19
Electronic information or services (www, Internet)		19
Specialists from NRCS and other government agencies		10
Television, radio, newspapers		7
Irrigation consultants hired by farm		5
Applied via irrigation system:		
Chemical fertilizer	Percent of acres	17
Pesticides	Percent of acres	8

Source: Estimated from the 1996 Agricultural Resource Management Survey (ARMS).

Irrigated corn yields averaged 154 bushels per acre, and water application rates averaged 10.5 inches per year. Groundwater was used for irrigation on almost 90 percent of irrigated corn area in Nebraska, Kansas, and Texas. Gravity irrigation systems were used on almost two-thirds of the acreage supplied by surface water. Gravity distribution is typically used with surface water sources because of lower water cost, level topography, and the older capital infrastructure built around such systems. Turbine pump technology, allowing extraction and pressurization of water at one point, makes it easier for groundwater-supplied farms to adopt sprinkler technologies, but at a substantial cost in higher energy requirements per acre-foot of water when compared with surface water. This can provide a strong incentive to increase groundwater irrigation efficiency. Thus, it was not surprising to find more lower-pressure, drop-tube center pivots among groundwater-supplied farms. Reducing the operating pressure directly translates into fuel cost savings.

Farmers producing irrigated corn operated an average of 5.5 wells per farm. Among irrigated farms, 64 percent of wells (serving 77 percent of the area irrigated) used backflow prevention devices to protect the water quality of aquifers, and 23 percent of wells had meters. Seventeen percent of irrigated corn acres received chemical fertilizer through the irrigation system. Pesticides were applied through irrigation systems to 8 percent of the irrigated area (table 10).

Comparison of Irrigated and Nonirrigated Systems

Comparisons of farm and farm operator characteristics of irrigated and nonirrigated operations are tenuous at best due to the small number of irrigated farm samples. However, the data may provide some insights for future research.

The most obvious difference between the two types of farms is their size. Irrigated farms had more than twice the acreage of nonirrigated farms and had a higher proportion of their total acreage in corn. The gross cash sales of farms with irrigation were almost double those of nonirrigated farms, reflecting larger acreage and higher yields. However, the share of gross cash sales from livestock, crops, government payments, and other sources was comparable, with irrigators having a smaller share from livestock. Over twice as many farms with irrigated corn had sales of $250,000 or more compared with nonirrigated farms, reflecting larger farms and higher irrigated yields (table 11).

The average age of operators of irrigated corn farms was 4 years less than that of operators of nonirrigated farms. Farmers with irrigated corn were almost twice as likely to have graduated from college as those without irrigated corn. About 25 percent of those with irrigation had their farm records computerized. Almost 90 percent of the farmers producing irrigated corn identified farming as their primary occupation.

Irrigated farms had a smaller percentage of their corn acreage in conventional, reduced, and mulch tillage than did nonirrigated farms, but a higher percentage in no-till/ridge-till. Both had the same share of acreage in highly erodible land (HEL), about 28 percent. The higher share of irrigated acreage in no-till/ridge-till reflects the use of ridge-till to create furrows for irrigation water flow. Ridge-till is typically the no-till system used by furrow irrigators (table 12).

Table 11—Operator and farm characteristics of farms raising irrigated corn and all farms raising corn, 1996

Item	Unit	Irrigators	All
Operator characteristics:			
Age	Years	48	52
Education:	Percent of farms		
High school or less		42	60
Attended college		29	26
Completed college		29	15
Farm records computerized		25	
Farm characteristics:			
Acres operated	Acres per farm	1479	612
Acres harvested--			
Corn		503	182
Soybeans		64	136
Wheat		174	37
Other		147	25
Gross cash sales:	$1,000 per farm		
Livestock		95	56
Crops		180	86
Government payments		18	6
Other		47	14
Sales class:	Percent of farms		
$0-$99,999		16	50
$100,000-$249,999		43	31
$250,000-$499,999		20	13
$500,000 or more		20	6
Acres harvested:	Percent of acres		
Corn		57	40
Soybeans		7	30
Wheat		20	8
Other		17	21
Gross cash receipts:	Percent of receipts		
Livestock		28	34
Crops		53	53
Government payments		5	4
Other		14	9
Specialization:	Percent of farms		
Cash grains		83	61
Livestock		16	34
Location:	Percent of farms		
Nebraska		79	
Kansas		11	
Texas		9	

Source: Estimated from the 1996 Agricultural Resource Management Survey (ARMS).

Table 12—Farm finances, corn enterprise yields, costs, returns, and input use on farms with irrigated corn and all farms raising corn

Item	Unit	Irrigated farms[1]	All farms
Farm finances:			
Income statement	$1,000 per farm		
Gross cash income		340	162
Variable cash expenses		227	90
Fixed cash expenses		59	30
Net cash income		54	43
Net farm income		64	42
Balance sheet	$1,000 per farm		
Assets		1,016	686
Liabilities		220	104
Equity		797	582
Debt-to-assets	Ratio	0.22	0.15
Return on equity	Percent	8.0	7.28
Corn enterprise:			
Actual yield	Bushels per acre	145	128
Expected yield		158	134
Costs and returns:	Dollars per planted acre		
Gross value of production		426	363
Total economic costs		436	358
Variable cash expenses		200	158
Land costs		102	86
General farm overhead		10	10
Taxes and insurance		25	23
Operating capital and capital replacement		99	88
Net returns above economic costs		-10	4.50
Unit costs:	Dollars per bushel		
Variable cash expenses		1.38	1.25
Total cash expenses		1.80	1.66
Economic costs		3.01	2.81
Input use:			
Seed	1,000 seeds per acre	28.8	27.2
Fertilizer:	Pounds per acre treated		
Nitrogen		160	134
Phosphorus		34	54
Potassium		26	74
Soil testing	Percent of farms using	75	31
Nitrogen testing		71	15
Pesticide:	Pounds of active ingredient per acre treated		
Herbicides		2.6	2.6
Insecticides		0.5	0.7
Scout for weeds	Percent of farms	82	70
Use commercial scouts		56	10
Scout for insects		80	54
Use commercial scouts		40	16
Manure	Tons per acre treated	0.4	6
Irrigation	Percent of acres	87	14
Continuous corn	Percent of farms	65	16
Tillage system:	Percent of acres covered		
Conventional		21	30
Reduced		26	32
Mulch		22	18
No-till/ridge till		31	20
Highly erodible land	Percent of acres	28	28

Source: Estimated from the 1996 Agricultural Resource Management Survey (ARMS).
[1]Data represent the average of irrigated plus nonirrigated acres on farms with irrigation.

Conclusions

The previous sections examined soil, nutrient, and irrigation management systems used in the production of corn, based on ARMS data for 1996. The characteristics of the practices, as well as those of the operators and the farms on which corn was produced, provide basic information for those interested in resource-use questions dealing with corn production. The information may be used by those working in the public arena to develop resource-use programs and policies that will meet both private and public objectives.

As new agricultural technologies emerge or established practices become widely recommended by public institutions, social scientists have asked why some farmers adopt a new technology and others do not. While this study does not address this question, it does identify some areas for future analyses. Productivity-enhancing practices and technologies were the focus of attention in early studies, but more recently attention has shifted to technologies that reduce negative environmental effects or conserve resources such as soil and water. Analysis of adoption behavior can help researchers and policymakers to adapt technologies and practices or design policy instruments that will encourage adoption. This report documents the extent of adoption of many of the most common soil, nutrient, and irrigation water management practices used on U.S. farms producing corn. It also examines selected operator, farm, and enterprise characteristics of the farms adopting various conservation strategies.

Tillage systems and structures designed to reduce soil erosion from intense rainfall are key components of most soil management and conservation systems. Conservation tillage, a widely recommended crop residue practice to conserve soil and reduce other environmental risks, was used on about 38 percent of the land in corn production in 1996. Other tillage systems that do not leave as much residue on the soil surface, such as reduced tillage and conventional systems, were used on 30 and 32 percent, respectively, of the corn acreage. The Lake States had the highest share of acreage in conventional tillage systems, while the Southeast had nearly 50 percent of its corn acreage in mulch-till or no-till. However, a major motivating force for adopting CRM (crop residue management) is the designation of a cornfield as HEL (highly erodible land).

Farmers who adopted conservation tillage systems (mulch- and no-till, specifically) tended to be younger and better educated than those using reduced-till and conventional systems. By nearly all size measures (acres or sales), farms producing corn with no-till practices were larger and less diverse (with relatively less livestock and fewer crop types) than farms using conventional tillage systems. Conservation tillage farms generated more income than farms using other tillage systems. However, producers adopting other tillage systems were not found to use significantly different levels of inputs to produce corn.

The survey results also show that two recommended nutrient management practices were each used on nearly 60 percent of the corn acreage: (1) corn-legume rotation, primarily using soybeans, and (2) application of nitrogen fertilizer to minimize surface runoff, either by methods other than broadcasting or by broadcasting followed by soil incorporation. Soil testing, applying all nitrogen at or after planting, and using precision agriculture technologies were each used on 20 to 30 percent of the corn acreage. Nitrogen inhibitors were used on less than 10 percent. At least four of the recommended practices were used by 12 percent of the farms; 19 percent used one or none of the practices.

Corn is one of the most widely irrigated crops in the United States, and as competition for water from nonagricultural sources intensifies, the importance of irrigation water conservation in corn production will likely increase. The ARMS estimated that 7 to 9 million acres of corn were irrigated in 1996. Most of this was in the moisture-deficient Plains States, primarily Nebraska, Kansas, and Texas. Forty-two percent of the irrigated corn was produced using gravity flow application systems and 39 percent using water-conserving sprinkler systems. The adoption of sprinkler irrigation technology and the use of irrigation information sources are identified as critical water conservation strategies.

This report is largely descriptive in nature. It leaves for further analysis questions about the empirical relationships between operator and farm characteristics and the adoption of management practices that can reduce negative environmental impacts from corn production. Identifying the farm and operator characteristics associated with specific practices and management systems may be useful in targeting education, technical assistance, and cost-sharing programs for nutrient management.

Suggestions for Future Research

Comparing producers who have adopted different soil, nutrient, or irrigation management practices and systems, even for the same commodity, poses several challenges, especially when a number of performance criteria are of interest. Roberts and Swinton (1996) note that "profitability and environmental impacts are the two performance criteria of greatest interest for contemporary comparisons…of different production or management systems."[5] They note that factors such as the dynamics of different systems (for example, crop rotations), responsiveness to shocks (weather and price changes), and environmental resource endowment (highly erodible soils and sandy soils over shallow aquifers), make multiobjective comparisons difficult across production or management practices. So do differences in human capital (such as age and education) and in attitudes about the environment. Further research needs to address how regional differences in soil and climate impact the selection of management practices. Some practices may be more appropriate and profitable in certain regions of the United States and for certain soil and agriclimatic zones. Analyzing a set of practices rather than each one individually helps offset the problem of circumstances that prevent use of a practice in a particular year. For example, adverse weather may prevent using a nitrogen inhibitor or broadcasting nitrogen during a year, or the producer may not employ a practice annually (as with soil testing).

A number of questions for future research arise from the data discussed in this report. Some concern the interrelationships between operator and farm characteristics and management practice selection. How important are age and education, compared with experience in making management system decisions? Do larger farms use more complex management systems, with more extensive sources of information and more explicit management linkages between soil, nutrient, and irrigation resources? How much does the income level and the balance sheet condition influence the choice of management systems? What implications do the relationships between farm size and adoption of management systems have for policy concerned with more benign environmental impacts? Do better managers control a larger asset base or have a significantly different return on equity than others? Is there a significant difference in the variable cost per bushel produced or the total cash expenses that can be related to operator characteristics and various management practices?

Other questions pertain to whether reasonable relationships can be established between the number of management practices adopted and the intensity of a corn producer's commitment to effective soil, nutrient, or irrigation management programs. What correlation can be assumed between the number of practices adopted and impacts on the environment and sustainable agricultural systems? Is reliance by producers on a set of practices, rather than a single specific practice, more effective in meeting the multiple objectives of resource management systems?

[5]They also point out that stability of income (i.e., risk) and environmental impacts are just as important as the average effect. However, this report focuses on the characteristics of the adopters of different management practices/systems in a static, rather than a dynamic, framework.

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Appendix A

Literature Review on the Adoption of Soil, Nutrient, and Irrigation Management Systems

The literature on the adoption of agricultural practices and technologies was surveyed to determine which factors might be expected to influence farmers' choices. These factors are identified in the ARMS dataset and reported to provide insights on the range of testable hypotheses that can be analyzed using these data.

Soil Management

A number of studies identify the factors or characteristics associated with farmers who have adopted conservation practices. Conservation tillage studies are the focus here. The numerous studies that examined other conservation practices, such as grassed waterways, contour farming, stripcropping, and terraces, are not discussed, except to note that: (1) they have found that education and perception of a soil erosion problem are positively associated with conservation practice adoption and (2) the proportion of land rented was significant and was negatively related (Ervin and Ervin, 1982; Norris and Battie, 1987; Young and Shortle, 1984).

A variety of economic, demographic, geographic, and policy variables have been identified that affect the adoption and use of conservation tillage in the United States. Management complexities and profitability are key factors impeding its adoption. The use of conservation tillage varies by crop and is dependent on site-specific factors, including soil type, topsoil depth, and local climatic conditions. The consensus of numerous studies is that the relative economic performance of any conservation tillage practice depends on a number of site-specific and operator-specific factors. The degree to which farmers are risk averse and soil type, topsoil depth, choice among cropping systems, level of managerial expertise, and local climatic conditions have all been identified as important variables.

In a study of Iowa farmers in 1976, Rahm and Huffman (1984) found that farmers with larger operations, a higher soybean-to-corn acreage ratio, and rolling, lighter, and better-drained soils were more likely to adopt conservation tillage. Human capital variables such as education, continuing operator education, and good health were found to positively impact the adoption decision. Norris and Batie (1987) reported on the conservation tillage decision of farmers in the Piedmont area of Virginia in 1983. They found that younger farmers and those that plan to transfer the farm to a relative operate more acres with conservation tillage. Farm size was also positively associated with acres under conservation tillage. Farmers with off-farm jobs and higher total incomes had fewer acres under conservation tillage. Norris and Batie did not find variables such as the operator's education and tenure status to be associated with conservation tillage acreage.

Belknap and Saupe (1988) examined factors influencing conservation tillage among farmers in southwestern Wisconsin in 1982. They found that adopters of conservation tillage were more likely to be risk takers and to be owners, to operate large farms, and to farm in areas with less precipitation and warmer climates. They also considered factors such as education, farming experience, family income, and debt-to-asset ratios, but did not find them to be important explanatory factors. A follow-on study in 1987 (Gould, Saupe, and Klemme, 1989) found the proportion of farm acres with conservation tillage to be positively associated with total farm acres planted, nondairy farms, sloping land, row crops, a dry, cool climate, and higher household income. Younger farmers and farmers who perceived an erosion problem on their land had a larger proportion of acres in conservation tillage.

Fuglie and Klotz (1994) studied the conservation tillage decisions made in 1991 by farmers in the Lower Susquehanna River Basin of Pennsylvania. They found having larger farms and farms subject to conservation compliance, as well as having fields with higher inherent soil erodibility, to be the only important variables differentiating farmers who used conservation tillage from those who used conventional tillage. Variables such as the operator's education or experience and the use of manure or planting of row crops were not important factors in their study. These results were confirmed in a more recent study by Caswell et al. (2001). They found that participation in farm programs and the use of technical advice had a positive influence on the probability of adopting conservation soil management practices, particularly practices with offsite benefits.

Much of the literature on adoption of new technologies focuses on why farmers differ in their willingness to adopt them (Antle and McGuckin, 1993; Westra and Olson, 1997). Among the reasons sug-

gested for adoption of conservation tillage are differences in entrepreneurial ability, risk preferences, and the availability of complementary inputs (Feder et al., 1985). Soil-conserving tillage systems are quite complex and normally require a higher level of management skills for the proper timing and placement of nutrients and pesticides. These managerial requirements have been found to be the key to successful use of conservation tillage (U.S. Department of Agriculture, 1997a). Conservation tillage provides fewer opportunities to correct mistakes or adjust to changed circumstances once the growing season is underway. New technologies must be integrated with existing inputs. In the case of conservation tillage, this implies that the system must be compatible with the soil characteristics and climatic conditions (Nowak, 1984 and 1992).

Several studies provide insight into the factors that affect the adoption of conservation tillage. Pagoulatos et al. (1989), using an erosion-damage function analysis for corn grown in Kentucky, found that the decision to convert to conservation tillage from conventional tillage is dependent on the price of output, the discount rate (with a higher rate leading to slower adoption), and the capital cost of conversion. Large capital costs for new machinery serve as a deterrent.

Uri (1997) found that cash grain enterprises were more likely to adopt conservation tillage than other farm types. Factors associated with a greater likelihood of adoption included the greater slope of the cropland and higher average rainfall. Adopters spent more on fertilizer and pesticides, but less on fuel, than nonadopters. Conversely, the age and education level of the farmer/operator was not associated with adopting conservation tillage. The productivity of the soil, as measured by average yield across farms in a county, had no identifiable impact. Texture of the soil, total acres planted, number of acres in the acreage reduction program, extent of irrigation, and proportion of acres not receiving any pesticide treatment likewise were not associated with the adoption of conservation tillage on corn acreage.

Batte et al. (1993) found that commercial farms in Ohio in 1992 tended to operate with a single system. Thus, farms classified as no-tillage used a no-tillage system on 85 percent of planted acreage, while conventional tillage farms used moldboard plowing on 80 percent of their acreage. Farms using conservation tillage tended to be substantially larger than farms using conventional tillage.

The greater volatility in yields or in net returns associated with the use of conservation tillage has been found to be a deterrent to its adoption. Mikesell et al. (1988) found conservation tillage systems had slightly higher expected returns but were more variable, based upon an evaluation of alternative tillage systems for a 640-acre grain farm in northeastern Kansas. Williams et al. (1989) found that conservation tillage used in grain sorghum production had higher expected net revenues but greater risk than conventional tillage.

Westra and Olson (1997) found that larger Minnesota farms are more likely to use conservation tillage and that the probability of this is greater if the owner/operator is more concerned about erosion.

Nutrient Management

Most adoption studies of natural resource management practices in agriculture have concentrated on medium- to long-term conservation practices such as conservation tillage, terraces, grassed waterways, contour farming, or stripcropping (Feder, Just, and Zilberman, 1985; Feder and Umali, 1993; Rahm and Huffman, 1984; Belknap and Saupe, 1988). Recent studies have looked at the adoption of nutrient management practices intended to increase nutrient use efficiency, and thus to decrease the harmful environmental effects of nutrient runoff and leaching into ground and surface waters. Fuglie, Bosch, and Keim (1994) and Fuglie and Bosch (1995) examined the adoption of soil and tissue nitrogen (N) testing by corn producers. The variables significant in explaining N-test adoption differed across regions studied. In Indiana, only the use of crop insurance was found to be a significant explanatory variable. In Pennsylvania, farmer experience was negatively associated with N-test adoption, while manure use had a positive impact. The explanatory power of the model was much greater when applied to Nebraska data. This model included policy and land quality variables as well as farm and farmer characteristics. Fuglie and Bosch found that irrigators were more likely than nonirrigators to use N-tests. N-test use was also higher on fields located in counties requiring a higher proportion of cropland to be N-tested. Farm operators who completed high school and at least some college were more likely to adopt N-testing than operators who had not finished high school. Farms with gross annual sales between $100,000 and $250,000 were less likely

to N-test than farms with lower gross sales. Operators used N-testing less on owned fields than rented fields and more on fields covered by crop insurance. Finally, N-testing was more likely to be practiced on sandy soils with above-average organic matter and pH. Variables hypothesized to be important in the decision to adopt N-testing but not found to be significant included operator experience, the presence of a USDA water quality project in the county, and whether a legume was grown in the field the previous season.

Cooper and Keim (1996) analyzed the nutrient management practices of legume crediting (estimating nitrogen amounts legumes collect from the air on their root nodules), nutrient value, manure testing, and split applications of nitrogen in Iowa, Illinois, Virginia, North Carolina, and Idaho. They found farm operators in Iowa and Idaho to be more likely than operators in Florida and Georgia to use legume crediting. Farmers who use rotations, manure, or tissue testing were more likely to adopt legume crediting. Education was positively associated with legume crediting, while the number of days worked off-farm showed a negative association. Beef, hog, and sheep farms were found less likely than others to use split nitrogen applications. The practice is also less common in Iowa. Manure testing was found to be more commonly adopted by operators who applied manure to the sampled field and by beef, hog, and sheep farms. Education was also a positive and significant variable in the manure-testing regression. Using the same survey data, Caswell et al. (2001) found that information-intensive nutrient management practices, such as soil testing or micronutrient use, were more likely to be adopted by farmers with more formal education, operators of larger farms, and those who sought technical advice.

In a number of studies, the operator's perception of an erosion problem was found to increase conservation expenditures or the number of conservation practices used (Belknap and Saupe, 1988; Ervin and Ervin, 1982; Gould et al., 1989; Norris and Batie, 1987). A similar variable for nutrient management, such as the perception of a nutrient problem in local water supplies, may significantly impact the decision to use nutrient management practices, but such a variable has not been measured by any study to date.

In summary, factors explaining the adoption of nutrient management practices are both regional and practice-specific. Adoption depends on the type of farming in the region (irrigated or not), the type of soils, and the presence of regulation. Some tests, such as manure testing, may more commonly be done on farms that have livestock. It is also likely that operators who believe that a nutrient problem exists in their own or their community's drinking water supply will be more likely to practice improved nutrient management, but this hypothesis has not been tested. Nutrient management is not one practice or set of practices likely to be adopted across the country by all operators. Rather, farm operators will choose among a suite of nutrient management techniques appropriate for their crops, soils, and level of regulation.

Irrigation Water Management Studies

Previous studies have examined the economics and field conditions associated with the adoption of improved irrigation technologies. Several of these studies were based in California (Caswell and Zilberman, 1985; Green et al, 1996; Caswell and Zilberman, 1986). Among the reasons for the California analysis was the availability of data to relate irrigation technology with crop production, soil quality, and field conditions. Most of these studies include a marginal water cost that helps explain why producers select advanced water management technologies. (Note that over the 10-year span of the California studies, the definition of "advanced" irrigation technologies changed.) All of these studies used cross-sectional data to statistically estimate multivariate adoption functions.

California is not the only place, nor is cross-section data the only base, for estimating the adoption of improved irrigation practices. Nieswiadomy (1988) used time-series data for seven counties in the Texas High Plains region to examine irrigation in an input substitution methodology, which included substitution among technology choices and farm labor. While this study did recognize the interaction between technology choice and other inputs (labor, in this case), it did not include the field-level data the California studies found important.

In a review of empirical research, Caswell (1991) found that the most significant factors influencing

water saving irrigation technology appeared to be land quality and water cost savings. Lichtenberg (1989) captured the simultaneous nature of the crop/technology choices. He showed that land quality exerts a marked influence on cropping patterns and that the introduction of center-pivot irrigation has induced changes in cropping patterns.

The field-level approach of Caswell and Zilberman (1985) was combined with the elements of Nieswiadomy's input substitution approach in a national examination of water-conserving technologies by Negri and Brooks (1996). Negri and Brooks used cross-sectional data and considered improvements to gravity irrigation and adoption of sprinkler technology separately. This study developed important procedures for examining field-level characteristics with a national database and showed that improving gravity irrigation systems is an effective alternative to replacing them with an entirely new technology.

Appendix B
Irrigation Systems and Land Treatment Practices

Gravity technologies
- Gravity irrigation from unlined ditches
- Gravity irrigation from lined ditches
- Poly pipe conveyance gravity irrigation
- Gated pipe gravity irrigation
- Cablegation and surge flow (improved) gated pipe irrigation

Basic sprinkler technologies
- Hand move and big gun sprinkler irrigation
- Solid set and side roll sprinklers
- Center pivot and linear move tower sprinklers with sprinklers on the main pipe

Improved sprinkler technologies
- Center-pivot and linear-move tower sprinklers with sprinklers below the main pipe (lower pressure systems with pressure regulators)
- Center-pivot and linear-move tower sprinklers with sprinklers less than 2 feet from the ground
- Variable rate center-pivot sprinklers

Other technologies
- Subirrigation by adjusting the water table level
- Low flow (drip/trickle)

On-farm water conveyance systems

Open-ditch conveyance systems may be earthen, although improved systems are typically lined with concrete or other less permeable materials to reduce seepage loss. Water is delivered to gravity-flow fields by siphon tubes, portals, or ditch gates, or pumped directly for certain pressurized systems.

Pipeline systems are often installed to reduce labor and maintenance costs, as well as water losses to seepage, evaporation, spills, and noncrop vegetative consumption. Underground pipeline constructed of steel, plastic, or concrete is permanently installed; above-ground pipeline generally consists of lightweight, portable aluminum, plastic, or flexible rubber-based hose. One form of above-ground pipeline—gated-pipe—distributes water to gravity flow systems from individual gates (valves) along the pipe. Pipeline systems are the predominant means of water conveyance for pressurized application systems.

Gravity-flow application systems

Furrow systems, the predominant gravity application systems, are distinguished by small, shallow channels used to guide water downslope across the field. Furrows are generally straight, although they may be curved to follow the land contour on steeply sloping fields. Row crops are typically grown on the ridge or bed between the furrows, spaced from 2 to 4 feet apart. Corrugations--or small, closely spaced furrows—may be used for close-growing field crops.

Border (or flood) systems divide the field into strips, separated by parallel ridges. Water flows downslope as a sheet, guided by ridges 10 to 100 feet apart. On steeply sloping lands, ridges are more closely spaced and may be curved to follow the land contour. Border systems are suited to orchards and vineyards and close-growing field crops such as alfalfa, pasture, and small grains.

Uncontrolled flooding is a gravity-flood system without constructed ridges, relying on natural slope only to distribute water across the field.

Improved gravity flow systems and practices

Field leveling involves grading and earthmoving to eliminate variation in field gradient—smoothing the field surface and often reducing field slope. Field leveling helps to control water advance and improve uniformity of soil saturation under gravity flow systems. Precision leveling is generally undertaken with a laser-guided system.

Level basin (or dead-level) systems differ from traditional border systems in that field slope is level and field ends are closed. Water is applied at high volumes to achieve an even, rapid ponding of the desired application depth within basins. Higher application efficiencies reflect uniform infiltration rates across the field and elimination of surface runoff. Precision laser leveling is required to achieve level fields suitable for this method.

Shortened water runs reduce the length of furrow (or basin) to increase uniformity of applied water across the field. Reduced water runs are most effective on coarse soils with high soil-water infiltration rates. Water runs of 1/2 to 1 mile in length may be reduced to 1/4 mile or less (with an appropriate reorganization of the on-farm conveyance system).

Surge flow is an adaptation of gated-pipe systems in which water is delivered to the furrow in timed releases. Furrows are alternately wetted and allowed to dry. As the soil dries, the soil surface forms a water seal, permitting the next surge of water to travel farther down the furrow with less upslope deep percolation. This technique significantly reduces the time needed for irrigation water to be distributed the full length of the field, thereby reducing deep percolation and increasing application efficiency.

Cablegation is a gated-pipe system in which a moveable plug is allowed to slowly pass through a long section of gated pipe, with the rate of movement controlled by a cable and brake. Due to the oversizing and required slope of the pipe, water will gradually cease flowing into the first rows irrigated after the plug has progressed sufficiently far down the pipe. Improved water management is achieved by varying the speed of the plug, which controls the timing of water flows into each furrow.

Alternate furrow irrigations involve wetting every second furrow only. This technique limits deep percolation losses by encouraging lateral moisture movement. Water applied and time required to irrigate each time may be significantly less than under full-furrow systems, but more irrigations may be required to supply crop needs. The technique is very effective when the desired strategy is to irrigate to a less-than-field-capacity level to more fully utilize rainfall.

Special furrows have been employed to enhance water management. *Wide-spaced furrows* function much like alternative-row irrigation, except that every row is irrigated and rows are farther apart. *Compacted furrows* involve compacting the soil in the bottom of the furrow to provide a smooth, firm surface to speed water advance. *Furrow diking* places dikes in the furrows to capture additional rainfall, thereby eliminating runoff and reducing irrigation requirements. Furrow diking is typically used on irrigated fields in combination with alternative furrow irrigations (in the nonirrigated row) or low-pressure sprinklers on fine textured soils.

Tailwater reuse systems recover irrigation runoff in pits below the field and pump the water to the head of the field for reuse.

Pressurized Application Systems

Center-pivot sprinklers are the predominant pressure technology. A center-pivot sprinkler is a self-propelled system in which a single pipeline supported by a row of mobile A-frame towers is suspended 6 to 12 feet above the field. Water is pumped into the pipe at the center of the field as towers rotate slowly around the pivot point, irrigating a large circular area. Sprinkler nozzles mounted on or suspended from the pipeline distribute water under pressure as the pipeline rotates. The nozzles are graduated from small to large so that the faster moving outer circle receives the same amount of water as the slower moving inside. Typical center-pivot sprinklers are one-quarter mile long and irrigate 128- to 132-acre circular fields. Center pivots have proven to be very flexible and can accommodate a variety of crops, soils, and topography with minimal modification.

Hand move is a portable sprinkler system in which lightweight pipeline sections are moved manually for successive irrigation sets of 40 to 60 feet. Lateral pipelines are connected to a mainline, which may be portable or buried. Hand-moved systems are often used for small, irregular fields. These systems are not suited to tall-growing field crops due to difficulty in repositioning laterals. Labor requirements are higher than for all other sprinklers.

Solid set refers to a stationary sprinkler system. Water supply pipelines are generally fixed—usually below the soil surface—and sprinkler nozzles are elevated above the surface. In some cases, hand-moved systems may be installed prior to the crop season and removed after harvest, effectively serving as solid set. Solid-set systems are commonly used in orchards and vineyards for frost protection and crop cooling. Solid-set systems are also widely used on turf and in landscaping.

Big gun systems use a large sprinkler mounted on a wheeled cart or trailer, fed by a flexible rubber hose. The machine may be self-propelled while applying water, traveling in a lane guided by a cable. Other systems may require successive moves to travel through the field. Big guns require high operating pressures, with 100 psi not uncommon. These systems have been adapted to spread livestock waste in many locations.

Side-roll wheel-move systems have large-diameter wheels mounted on a pipeline, enabling the line to be rolled as a unit to successive positions across the field. A gasoline engine generally powers the system movement. This system is roughly analogous to a hand-moved system on wheels. Crop type is an important consideration for this system, since the pipeline is roughly 3 feet above the ground.

Improved Pressurized Systems and Practices

Improved center pivots have been developed that reduce water application losses and energy requirements. Older center pivots, with the sprinklers attached directly to the pipe, operate at relatively high pressure (60-80 psi), with wide water spray patterns. Newer center pivots usually locate the sprinklers on tubes below the pipe and operate at lower pressures (15-45 psi). Many existing center pivots have been retrofitted with system innovations to reduce losses and energy needs.

Linear or lateral-move systems are similar to center-pivot systems, except that the lateral line and towers move in a continuous straight path across a rectangular field. Water may be supplied by a flexible hose or pressurized from a concrete-lined ditch or along the field edge.

LEPA (*Low-energy precision application*), is an adaptation of center-pivot (or lateral-move) systems that uses droptubes extending down from the pipeline to apply water at low pressure below the plant canopy, usually only a few inches above the ground. Applying the water close to the ground cuts water loss from evaporation and wind and increases application uniformity. On fine-textured soils with slower infiltration rates, furrow dikes may be necessary to avoid runoff.

Low-flow irrigation systems, including *drip* and *trickle*, use small-diameter tubes placed above or below the field surface. Frequent, slow applications of water are applied to soil through small holes or emitters. The emitters are supplied by a network of main, submain, and lateral lines. Water is dispensed directly to the root zone, precluding runoff or deep percolation and minimizing evaporation.

Microsprinklers, a variation of low-flow systems, use the same type of supply system, with low-volume sprinkler heads located about 1 foot above the ground. (Microsprinklers are used in place of multiple drip emitters when wetting an area or perimeter is necessary.) Low-flow systems are generally reserved for perennial crops, such as orchard products and vineyards, or other high-value vegetable crops (USDA, 1997b).

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