4.4 Nutrient Use and Management

Nutrients, which need to be applied to most fields to maintain high crop yields, have been associated with air and water quality impairment. While exceptions occur in some areas of the country, most nutrients applied in the U.S. are from commercial fertilizers. Commercial fertilizer use exceeded 20 million nutrient tons per year since 1990 and rose to over 22 million tons during the 1996-98 fertilizer years because of increased area planted. Fertilizer prices paid by farmers were stable from 1989 to 1993, rose dramatically in 1994 and 1995, and, for most nitrogen products, declined to below 1993 levels between 1996 and 1999. Many improved practices are available to reduce nutrient losses to the environment, with varying degrees of adoption by farmers. To improve nutrient management, farmers need to understand the link between agricultural production and the environment, and public policies need to encourage farmers to adopt resource-conserving practices.

Contents *Page*

Role of Plant Nutrients

Crops and other plants take up nutrients from the soil as they grow. The major nutrients are nitrogen (N); phosphate (P_20_5), the oxide form of phosphorus (P); and potash (K_20), the oxide form of potassium (K). (See Glossary for more on the roles of nutrients in food and fiber production.) Crops also require other nutrients for growth and development, including magnesium, calcium, and sulphur, but in smaller amounts. Sulphur, for example, is important to plants for protein formation. Nutrients that crops need in only small or trace amounts (called micronutrients) include boron, chlorine, copper, iron, manganese, molybdenum, cobalt, sodium, and zinc. Commercial fertilizers are applied by farmers to ensure sufficient nutrients for high crop yields. Lime is also applied to some soils as a soil amendment, rather than as a nutrient. Lime reduces soil acidity (pH) so that crops can better utilize available nutrients and micronutrients.

From the settlement of the United States until the 19th century, increased food production came almost entirely from expanding the cropland base and mining the nutrients in the soil. However, the expanding demand for agricultural commodities required soil nutrient replacement to maintain or expand crop yields. First, manure and other farm refuse were applied to the soils. Later, applications of manure were supplemented with fish, seaweed, peatmoss, leaves, straw, leached ashes, bonemeal, and Peruvian guano, materials that contained a higher percentage of nitrogen, phosphate, and potash than did manure (Wines, 1985). As manufacturing developed, production of chemical fertilizers like superphosphates and, later, urea and anhydrous ammonia (see

Glossary of Fertilizer Terms) replaced most fertilizers produced from recycled wastes. Commercial fertilizers provided low-cost nutrients to help realize the yield potential of new crop varieties and hybrids (Ibach and Williams, 1971). If nutrients were not applied, today's crops would rapidly deplete the soil's store of nutrients, and yields would decline.

Why Manage Nutrients?

Profitable crop production requires significant amounts of nutrients in the form of commercial fertilizers and animal wastes, portions of which can subsequently run off into surface waters or leach into groundwater. The two primary agricultural nutrients affecting water quality are nitrogen and phosphorus. Nitrogen, primarily found in the soil as nitrate, is soluble and easily transported by surface runoff, in tile drainage, or by leachate. Phosphorus, primarily in the form of phosphate, is not as soluble as nitrate and is primarily transported by sediment in runoff. However, phosphorus can also be transported in soluble form, particularly phosphorus contained in animal wastes (Southern Cooperative Series, 1998).

Excessive nitrogen or phosphorus in surface waters can cause algae to grow at an accelerated rate and cloud water, which prevents aquatic plants from receiving sunlight for photosynthesis. When the algae die and are decomposed by bacteria, they deplete the oxygen dissolved in the water and threaten aquatic animal life. This process, eutrophication, can result in clogged pipelines, fish kills, and reduced recreational opportunities or enjoyment. According to the U.S. Environmental Protection Agency (EPA), nutrient pollution is the leading cause of water quality impairment in lakes and estuaries and the third leading cause in rivers (1995). Nitrate is also a concern for drinking water, when present above a certain concentration. Based on the human health effects, EPA has established a maximum contaminant level of 10 mg/liter for nitrate in public drinking systems.

Nutrient pollution of water resources can occur because of unusually wet weather that increases nutrient leaching and runoff. It can also occur when farmers are unaware of the offsite effects of their production decisions, or when they have no assigned cost or penalty for those effects and so choose production systems that may have greater profitability or less economic risk but higher nutrient losses. (For more on water quality impacts of agriculture, see Chapter 2.3).

Nutrient Sources

Commercial fertilizer is by far the major source of applied plant nutrients in the United States, followed by animal manure. Treated or composted municipal and industrial wastes are applied as sources of plant nutrients in some areas, but little data are available and overall use is likely limited, although increasing. Specific aspects of these three sources of applied nutrients are described below.

Commercial Fertilizer

The U.S. commercial fertilizer industry is essentially composed of three separate industries (nitrogen, phosphate, and potash). Each has different material and process requirements but they are both horizontally and vertically integrated (Andrilenas and Vroomen, 1990).

Anhydrous ammonia is the source of nearly all nitrogen fertilizer. It may be applied directly to the soil or converted into other nitrogen fertilizer such as ammonium nitrate, urea, nitrogen solutions, synthetic ammonium sulfate, and ammonium phosphate. Anhydrous ammonia is synthesized through a chemical process that combines atmospheric nitrogen with hydrogen. Nitrogen can be obtained from the air, but the hydrogen is derived from natural gas.

U.S. capacity to produce anhydrous ammonia and other nitrogen fertilizers increased after 1950 in response to rising demand. Capacity increased from 7.8 million tons in 1964 to 20 million tons in 1981, declined to about 17 million tons in 1995 due to plant closures and lack of new plant construction, and rebounded to 20 million tons by 1999 (International Fertilizer Development Center, 1999). Plants built before 1960 were scattered around the country in areas of high market demand. Plants built since then, however, are located near natural gas regions of the Delta (Mississippi, Arkansas, and Louisiana) and the Southern Plains (Texas and Oklahoma).

The United States is a net importer of nitrogen. In 1998, the United States exported more than 3 million nutrient tons of nitrogen and imported over 5 million nutrient tons; however, imports are understated because anhydrous ammonia imports from the former Soviet Union are not reported by the Department of Commerce due to a disclosure claim. The major nitrogen fertilizer import is anhydrous ammonia while the major export is diammonium phosphate, which contains 18 percent nitrogen and 46 percent P_20_5.

Nearly all phosphate fertilizer is produced by treating phosphate rock with sulfuric acid to produce phosphoric acid, which is further processed into various phosphatic fertilizer materials such as superphosphates and ammonium phosphates. The United States has become the world's largest phosphate fertilizer exporter. Approximately 1.7 tons of phosphate rock and about 1.3 tons of sulfuric acid are required to produce a ton of diammonium phosphate. U.S. annual phosphoric acid capacity is nearly 14 million tons of P_20_5. Phosphate rock is obtained from mines mainly in Florida and North Carolina, with annual capacity estimated at 62 million tons.

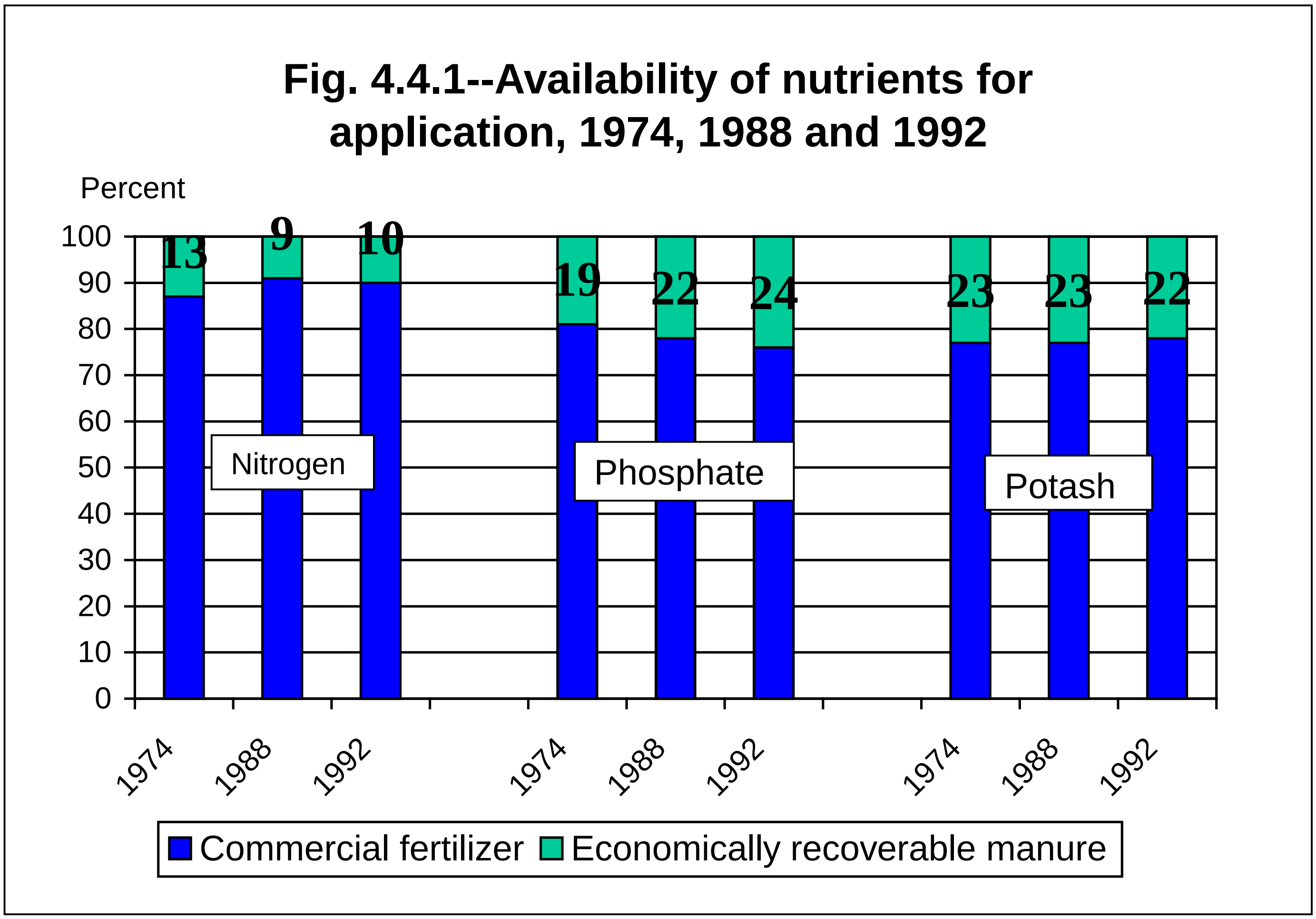
Potash can be used as a fertilizer with less processing or refining than nitrogen or phosphate. Most potash deposits in the United States are located near Carlsbad, New Mexico. However, these deposits supply less than 10 percent of U.S. demand. Vast potash deposits in Saskatchewan and New Brunswick, Canada, are cheaper to mine than the dwindling U.S. reserves because of the large size, uniformity, and high quality of the Canadian deposits, and the modern mining techniques used. The United States currently imports over 5 million tons of potash per year and over 95 percent of these imports come from Canada. U.S. and Canadian annual potash capacity is about 1.1 and 13.9 million tons of K_2O, respectively.

Calcium, magnesium, and sulfur are often added to soils to correct plant conditions such as failure of leaves to unfold or fruit to develop, yellowing between veins of older leaves, and pale yellow or light green leaves. Applying lime to bring soil pH into proper range for optimum plant growth usually supplies sufficient calcium. Primary sources of calcium are liming materials and gypsum, which are considered soil amendments rather than fertilizers. The most common source of magnesium is dolomite limestone, which contains up to 12 percent magnesium (The Fertilizer Institute, 1982). The main forms of sulfur in soil are inorganic sulfates and sulfur in organic matter. Atmospheric sulfur dioxide had been a major source of sulfur for crops, but as atmospheric emissions of sulfur dioxide are reduced by environmental controls, the sulfur needs of crops must be supplied by fertilizer sources.

Availability of micronutrients to plants is related to soil pH. Availability of boron, copper, iron, manganese, and zinc generally decrease as soil pH increases from 5 to 7, while the availability of molybdenum increases. Micronutrients are involved in cell division, photosynthesis, fruit formation, carbohydrate and water metabolism, chlorophyll formation, protein synthesis, and seed development in plants. Micronutrient needs during different stages of plant growth must be better understood so that sufficient supplies are made available.

Animal Manure

Animal waste is primarily manure, but on some large poultry operations, dead chickens are also a disposal problem and a source of nutrients if properly composted. In recent years, animal wastes have provided 9-24 percent of total nutrients available for crop production (fig. 4.4.1). Because of transportation costs, use of animal waste as fertilizer is economically feasible only if on-farm or nearby sources exist, and thus occurs on



relatively few acres. For example, among the major field crops, the share of acres treated with manure ranges from about 15 percent for corn and 10 percent for soybeans to less than 3 percent for wheat.

In 1992, there were 435 million acres of cropland, of which 124 million, or 28 percent, were farmed by producers having confined animal units. These 511,000 farms had 60.7 million animal units of beef, dairy, swine, turkey, and poultry (Letson and Gollehon, 1996), producing an estimated 1.23, 1.32, and 1.44 million tons of economically recoverable nitrogen (N), phosphate (P_2O_5), and potash (K_2O). Letson and Gollehon (1996) also determined that large specialized animal production farms produce most animals but have little cropland. Facilities with fewer animals produce a minor share of the animals but have a large share of the cropland associated with confined livestock farms. Concentration of increasing numbers of animals on fewer farms has been a long-term trend. The significance of the shares of animals and acres is that, historically, a large share of manure did not leave the farm where it was produced (Bosch and Napit, 1992). High-density areas like dairy farms in southern California, beef feedlots in the Southern Plains, large hog operations in the Corn Belt, and the broiler belt across the Delta, Southeast and Appalachian States provide large quantities of manure that is likely underused as fertilizer. However, some areas have both high manure nutrient densities and high fertilizer spending per acre, suggesting redundant nutrient applications that may be an avoidable farming expense and that could impair water resources (Letson and Gollehon, 1996).

Environmental degradation, particularly of water, can occur from excessive use or improper handling or application of nutrients (Achorn and Broder, 1991; Bosch, Fuglie, and Keim, 1994; Kanwar, Baker, and Baker, 1988; and Kellogg, Maizel, and Goss, 1992). Large livestock operations are already under regulation as point sources of pollution, requiring installation of certain facilities and practices. In many critical areas, USDA is helping smaller livestock operations efficiently manage animal and commercial nutrients to reduce their loss to the environment. (For more on USDA water quality programs, see Chapter 6.4).

Municipal and Industrial Wastes

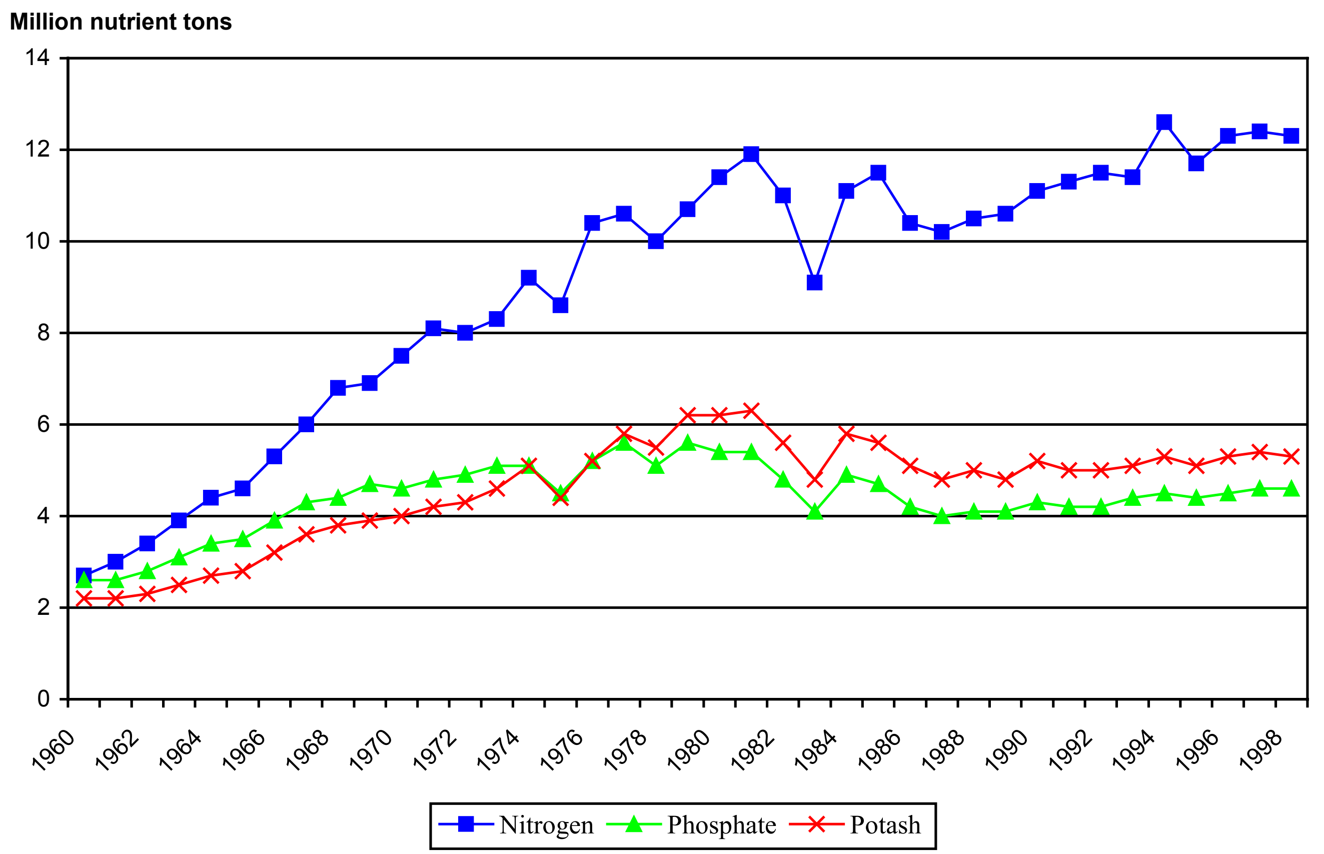
Municipal wastes include municipal solid wastes (MSW) and sewage sludge (SS). America's cities generated 200 million tons of MSW in 1990 (Millner, and Others, 1993). MSW includes paper and paperboard, glass, metals, plastics, rubber, leather, textile, wood, food wastes, yard trimmings, miscellaneous inorganic wastes, and other residential, institutional, and industrial wastes. The three major methods for MSW disposal in 1990 were land filling (61 percent), recoveries for recycle (17 percent), and incineration (12 percent). SS is collected at municipal wastewater plants. The three major methods of SS disposal in 1988 were land application (36 percent), surface water disposal (10) percent, and incineration (3 percent) (the rest of SS disposal is either not regulated or unknown). About 27 percent of SS was applied to agricultural land. A small portion (about 1.2 percent) of SS was used for composting in 1988. The number of municipal wastewater plants producing SS compost increased from 90 in 1983 to 318 in 1994 (Golstein, Riggle, and Steuteville, 1994). The outlets for SS compost are public works applications; wholesale marketing to soil blenders, landscapers, and nurseries; and giveaways to the public.

Commercial Fertilizer Use and Product Change, 1960-98

U.S. nitrogen, phosphate, and potash use for all purposes rose from 7.5 million nutrient tons in 1960 to a record 23.7 million tons in 1981 (table 4.4.1). Total nutrient use dropped from this level, along with total crop acreage, to 21.3 million nutrient tons in 1995. Aggregate nutrient use has increased slightly over the the 1996-98 period to over 22 million nutrient tons.

Nitrogen, phosphate, and potash all contributed to the dramatic increase in fertilizer use during the 1960's and 1970's (table 4.4.1, fig. 4.4.2), although nitrogen use increased most rapidly. In 1960, nitrogen use was about 37 percent of total commercial nutrient use; by 1981, nitrogen use had increased 335 percent and represented over 50 percent of total commercial nutrient use. Nitrogen use equaled 12.3 million tons in 1998, or 55.4

Fig. 4.4.2--U.S. commercial fertilizer use, 1960-98



percent of total commercial nutrient use. This relative gain in nitrogen use is the result of increased farmer demand stemming primarily from favorable crop yield responses, especially corn, to nitrogenous fertilizers.

Phosphate's share of total commercial nutrient use declined from 34.5 percent in 1960 to 20.5 percent by 1998 (table 4.4.1). Potash use, historically below that of both nitrogen and phosphate, exceeded phosphate use for the first time in 1977 and will likely hold this position. In 1998, potash accounted for 24.1 percent of total fertilizer use.

Fertilizer products have changed over time. In 1960, mixed fertilizers (containing two or more nutrients) constituted almost 63 percent of total fertilizer consumption (Vroomen and Taylor, 1992). This share declined to 35 percent in 1998. The share of direct application materials (containing primarily one nutrient) increased from 37 percent to 65 percent during this period. The use of major direct-application nitrogen materials increased through the early 1980's (Fertilizer Institute, 1982). High-analysis products such as anhydrous ammonia, nitrogen solutions, and urea benefited from economies in transportation, distribution, and storage, and from the ease and accuracy of applying nitrogen solutions.

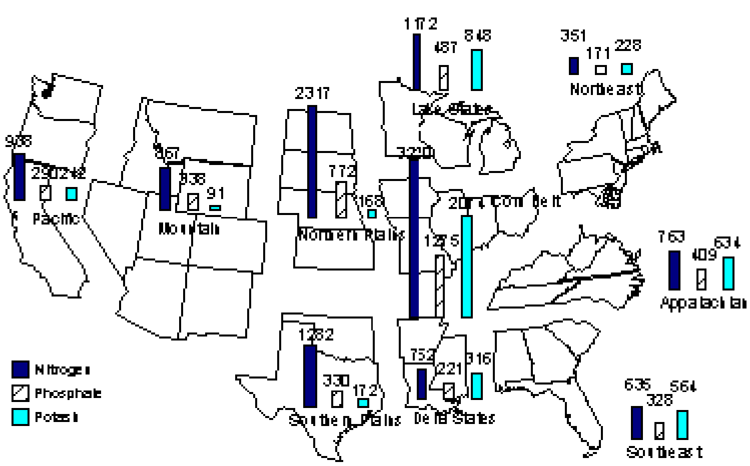
Directly applied phosphate fertilizer products have declined since the early 1970's because of the increased use of diammonium phosphate (DAP). The trend throughout the 1960's and 1970's was toward increased use of triple superphosphates (products that contained a higher percentage of phosphate) relative to normal superphosphates because of transportation, distribution, and storage economies. Since 1979, consumption of both normal and triple superphosphate has declined. The use of DAP, a mixed fertilizer containing 18 percent nitrogen and 46 percent phosphate, has dramatically increased since the 1960's (Tennessee Valley Authority, 1994).

The use of potassium chloride, the major directly applied potash fertilizer containing about 60 percent potash, has also greatly increased since the 1960's. Total use of potash reached a record 6.3 million tons in 1981, up from 2.2 million tons in 1960. Potash use has fallen to slightly more than 5 million tons during the 1990’s.

Fertilizer Use by Region and Crop

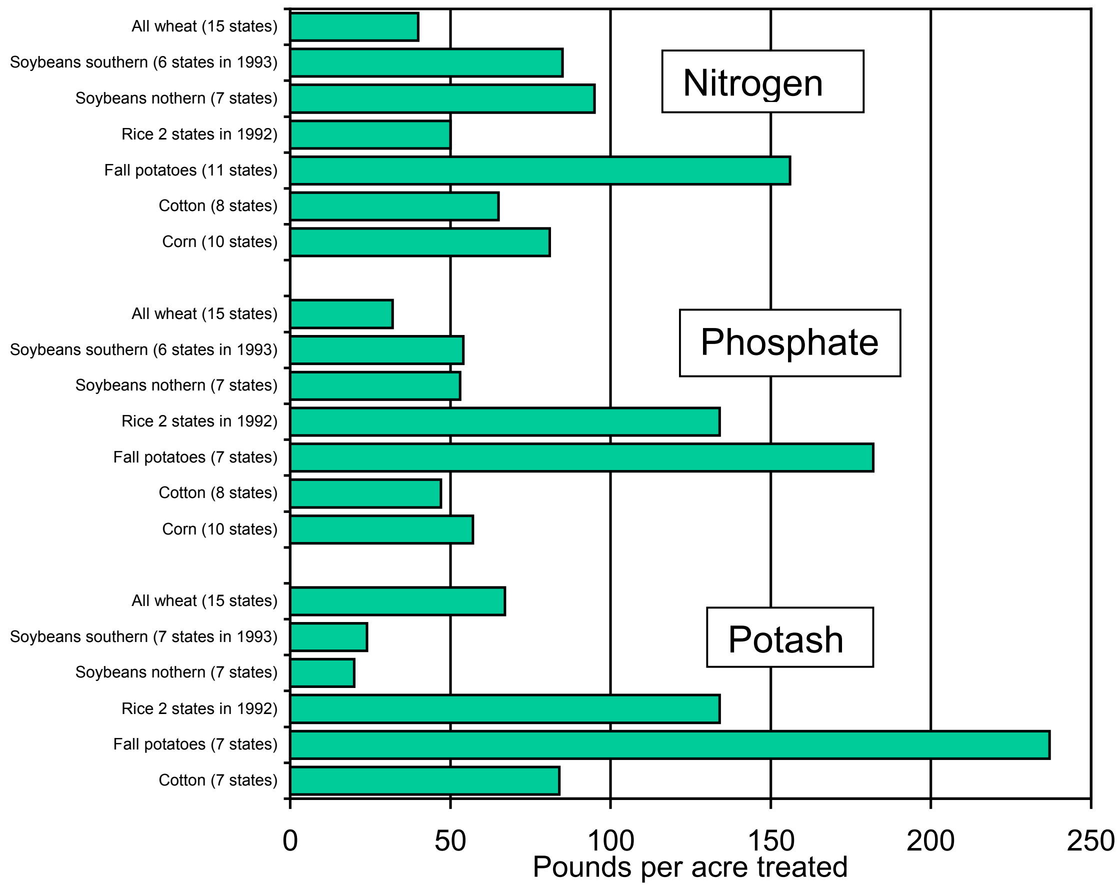
The Corn Belt (Ohio, Indiana, Illinois, Iowa, and Missouri), with its large crop acreage, uses more commercial fertilizer than any other region (fig. 4.4.3). However, from 1985 to 1993, nitrogen use in the Corn Belt decreased from 3.4 to 3.0 million tons, but then increased to 3.5 million tons in 1994 following the 1993 flood (table 4.4.2). Nitrogen use in the Corn Belt was slightly over 3.2 million tons in 1997 and 1998. Phosphate use decreased from 1.5 million tons in 1985 to 1.3 million tons in 1998 and potash use decreased from 2.3 to 2.1 million tons. Fertilizer use is highly dependent on soil type and condition, crop mix, planting methods, and planted acres (Meisinger, 1984; Nelson and Huber, 1987; Mengel, 1986; Pierce and others, 1991; Rhoads, 1991; and Scharf and Alley, 1988). Fewer crop acres have been planted in the Corn Belt since 1981 because of government programs such as the Acreage Reduction Program (ARP) and the Conservation Reserve Program (CRP). Thus, total fertilizer use in the Corn Belt declined during the 1980’s and remained relatively constant during the 1990’s. In the areas flooded in 1993, additional nutrients were applied in 1994 in excess of normal application rates to replenish flood-damaged soils. In the Northern Plains region (North Dakota, South Dakota, Nebraska, and Kansas), the second highest user of nitrogen and phosphate, nitrogen use increased from 1.8 million tons in 1985 to 2.3 million tons in 1998 (table 4.4.2).

Figure 4.4.3--Regional commercial nutrient use, year ending June 30, 1998



Fertilizer use among crops differs significantly (Vroomen and Taylor, 1992; USDA, 1995). Nearly all acres in corn, fall potatoes, and rice, and over three-fourths of cotton and wheat acres received some form of commercial fertilizer (table 4.4.3). The most frequently applied nutrient was nitrogen. In contrast, less than 40 percent of the acres in soybeans, a nitrogen-fixing crop, received commercial fertilizer applications in 1997 (table 4.4.4). Nitrogen application rates have been highest for fall potatoes, averaging 237 lbs. per acre in 1997, followed by corn (fig. 4.4.4, table 4.4.5). Fall potatoes also have the highest rate of both phosphate and potash applications, two

Fig. 4.4.4--Average application of commercial fertilizer, selected crops, 1997

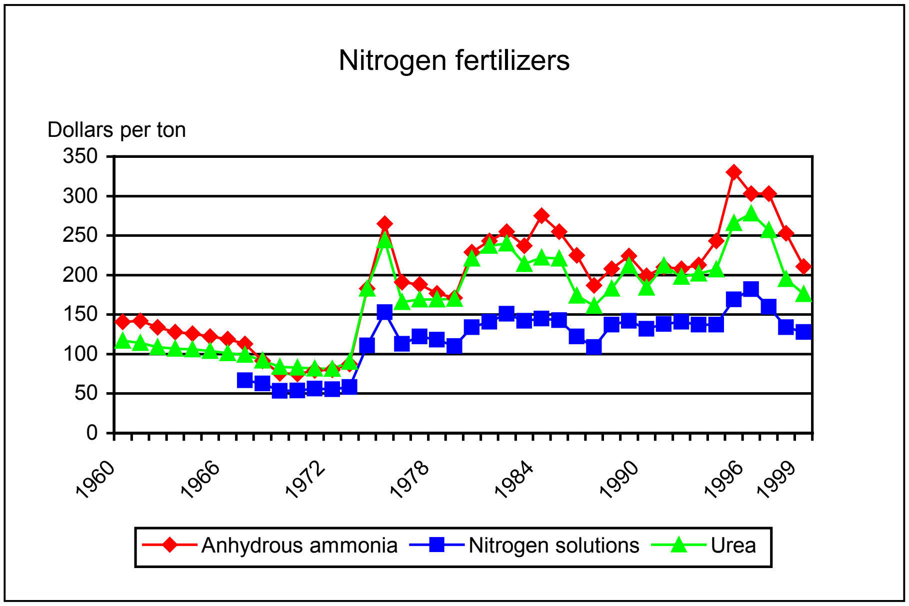


to three times the rates for other major field crops. Nitrogen applicatin rates on corn dropped from 137 lbs. per acre in 1988 to 123 lbs. per acre in 1993, but increased to over 130 lbs. in 1996 and 1997. The percentage of various crops receiving fertilizer, and fertilizer application rates, varies among the major growing States (USDA, 1997 and appendix tables 4.4.15 through 4.4.20 hyperlink to .xls file for 1997 State data).

The share of acres receiving lime, sulfur, and micronutrients also varies by crop (tables 4.4.3 and 4.4.4). For example, only about 9 percent of wheat acres have ever received lime while about 59 percent of northern soybeans and 15 percent of fall potatoes have ever been treated with lime. Lime application rates average between 1 and 2.5 tons per acre depending on the crop (table 4.4.5). Almost 64 percent of potato acres received an average of 76 pounds of sulfur in 1997. Other crops received between 11 and 18 pounds per acre in 1994 with acres receiving sulfur ranging from 1 to 20 percent. Over 70 percent of potato acres surveyed in 1996 and 1997 received micronutrients.

Factors Affecting Fertilizer Use

The principal factors affecting total commercial fertilizer use are the level and mix of planted cropland, fertilizer



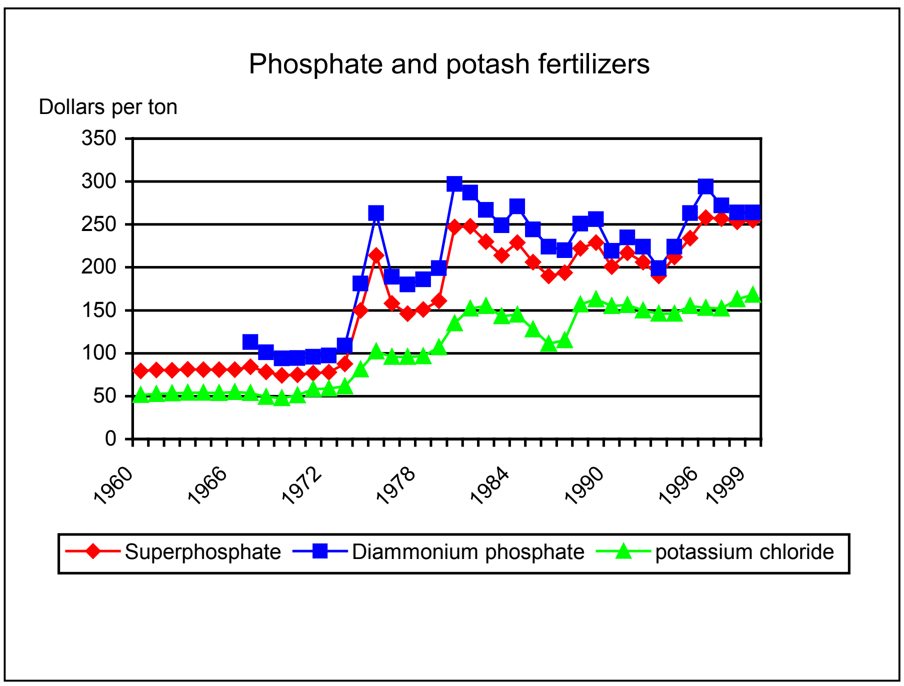


Fig. 4.4.5--Average farm prices of selected fertilizers, 1960-99

prices, and commodity prices and programs (Denbaly and Vroomen 1993). Other factors influencing farmers' fertilizer use decisions on specific fields include soil characteristics, climate and weather, crop rotations, application technology, and nutrient management practices.

Crop Acreage--Acreage of principal crops has varied over the years, ranging from 300 million acres in 1970 to 372 million acres in 1981. Since then, acreage has varied between 315 million and 340 million acres. In 1998, acreage of principal crops planted equaled 329 million acres.

Acreage planted and crop mix are dependent on many factors, including government programs, weather, expected commodity prices, input costs, and export markets. Acres planted to corn and wheat greatly affect fertilizer use and prices. Corn is the crop that uses the most fertilizer, accounting for over 42 percent of all use, while wheat is second at 16 percent. Planted corn acreage has ranged from 60 to 85 million acres over the past 30 years and planted wheat acreage has ranged from 53 to 88 million acres. In 1997, approximately 80 and 71 million acres were planted to corn and wheat. To the extent that CRP acreage comes back into production as a result of contract expiration and higher crop prices, nutrient use could expand.

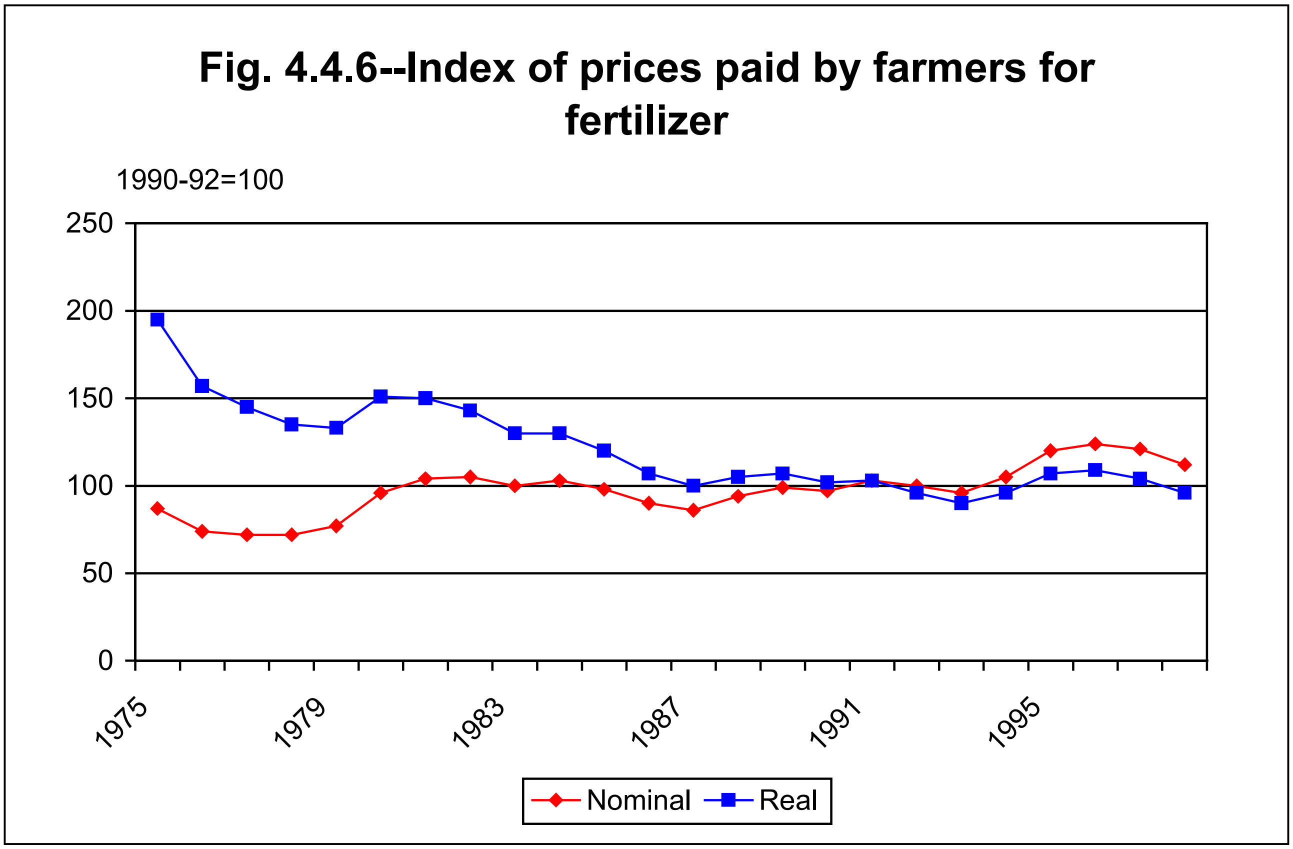
Fertilizer Prices--Fertilizer use in the United States has historically been inversely related (but relatively unresponsive) to changes in fertilizer prices, particularly in the short run. Analyses have found elasticities (the percentage change in fertilizer use per percentage change in fertilizer price) to run upwards from -0.19 in the short run and from -0.31 in the long run (after farmers have had adequate time to adjust operations) (Griliches, 1958; Denbaly and Vroomen, 1993). In some major Corn Belt States, the elasticities may be even less. One analysis of Indiana and Illinois data--using a model that allowed short- and long-run substitution among agricultural inputs (hired labor, feeds, seeds, fertilizer, pesticides, fuels, and capital) and that included a weather index--found elasticities of about -0.07 for corn both in the short and in the long run (Fernandez-Cornejo, 1993).

Individual fertilizer product prices vary from year to year and substitution among products within nutrient groups does occur. Annual price changes among products can result in different combinations of products used by farmers from year to year.

Fertilizer purchases have historically represented about 6 percent of total farm production costs. Total expenditures on fertilizer by U.S. farmers in 1997 were estimated at $10.9 billion, up 18 percent over 1994. The increase in expenditures is a combination of increased fertilizer prices, increased planted acres, and increased application rates for corn over 1994. Fertilizer price declines in 1998, especially for nitrogen products, resulted in fertilizer expenditures falling to an estimated $10.5 billion.

Fertilizer prices have changed less than other agricultural inputs during the last 10 years. For example, nominal prices farmers paid for fertilizers increased 18 percent from 1984 to 1995 while wage rates went up 51 percent, farm machinery increased 40 percent, agricultural chemicals other than fertilizers increased 28 percent, and seeds went up 16 percent.

Farm fertilizer prices fell during 1983 and again in 1985/86 as a record level of crop acreage was diverted, first by the payment-in-kind program (PIK) and later by the ARP and CRP programs (Vroomen and Taylor, 1992). Prices rose steadily from 1986 to 1989 (table 4.4.6, fig. 4.4.5). Prices of most fertilizer materials fell from 1989 levels, but remained relatively stable through 1992 (Taylor, 1994). The prices U.S. farmers paid for many fertilizer materials rose significantly between 1993 and 1995. For example, the price of anhydrous ammonia increased 64 percent from October 1993 to April 1995 to a record high of $330 per ton. Diammonium phosphate's price increased 37 percent over this time period. Other fertilizer products also increased, but not as much. Real fertilizer prices (fertilizer price index adjusted by the implicit price deflator of the United States) have declined from an index of 195 in 1975 to 110 in 1995 using 1990-92 as a base (fig. 4.4.6). In constant dollars, farmers paid 44 percent less for fertilizer in 1995 than they did in 1975.



The increase in fertilizer prices between 1993 and 1995 resulted from tight world supplies and increased demand. For example, anhydrous ammonia use increased 26 percent from 1993 to 1994 and total nitrogen use increased over 11 percent due to an increase in corn acres (corn uses about 45 percent of all fertilizer). Increases in planted acres of soybeans, cotton, and rice also contributed to an increased demand for fertilizer. Nitrogen application rates on corn increased from 123 to 129 pounds per acre in 1994-95 following the 1993 flood; phosphate and potash application rates also increased. In addition, weather conditions were ideal for the direct application of anhydrous ammonia. There was also an increase in non-agricultural demand for nitrogen in products such as adhesives, plastics, resins, and rubber. During 1995, U.S. fertilizer exports increased over 1994 because of China's increased demand for diammonium phosphate and other fertilizer products.

On the supply side, several factors placed upward pressure on fertilizer prices during 1994 and 1995, including higher priced imports from the former Soviet Union, unscheduled repairs that caused plant closings, low inventories, and an explosion that temporarily closed a large nitrogen production plant. The United States is a net importer of ammonia. Since 1990, U.S. ammonia demand has exceeded U.S. supplies while nitrogen plants have been producing in excess of 100 percent capacity. These factors have occurred during a period in which both agricultural and industrial demands have been growing and ammonium phosphate exports have risen.

Fertilizer prices have declined since 1996. During 1997 and 1998, China limited urea and other fertilizer imports to protect its domestic production. Reduced world demand for fertilizer products because of weakened economic conditions in the former Soviet Union and Asia combined with increased world capacity has put downward pressure on prices. Phosphate and potash prices have remained stable into 1999, but nitrogen prices continued to decline. For example, U.S. anhydrous ammonia prices fell over 35 percent from 1995 to 1999, as world nitrogen supply has increased and demand has remained stagnant.

Commodity Prices and Programs--Commodity programs can directly influence fertilizer use through planted acreage or application rates. The U.S. Government supported crop prices for over half a century by lending farmers money at varying loan rates, using crops as collateral and guaranteeing minimum crop prices (target prices set by law). When market prices of commodity program crops were lower than target prices, participating farmers could receive from the Government deficiency payments for crops planted to base acreage. Deficiency payments were the difference between the target price and the higher of the loan rate or average market price. Participation in commodity programs provided farmers with a more stable farm economy over time; however, participation also required some land to be idled (CRP and ARP programs). Analyzing data from the 1991 and 1992 Cropping Practices Survey, Ribaudo and Shoemaker (1995) determined that economic incentives from participation in commodity programs caused program participants to apply fertilizers at greater rates than nonparticipants.

The Federal Agriculture Improvement and Reform Act of 1996 continued the trend toward greater market orientation of government farm programs (Young and Wescott, 1996). The Act increased farmer's planting flexibility and eliminated annual supply management policies (i.e., ARP's were eliminated) which permitted farmers to more quickly respond to changing market conditions. However, the CRP was maintained which is currently the principal policy instrument that limits cropland availability and constrains crop production. The Act authorizes the CRP to be maintained at slightly over 36 million acres. Greater market orientation may lead to increased volatility in the cropping mix which in turn could introduce additional uncertainty in the fertilizer markets as farmers attempt to maximize income by shifting acreage between competing crops. However, due to the downturn in agricultural exports in 1998, the effects of the farm programs on crop mix appear to have reappeared. For example, declining prices for both corn and soybeans resulted in farmers' planting decisions being based on the loan rates and expected loan deficiency payments of these two commodities. One analysis indicated that an additional 1.7 million acres of soybeans was expected to be planted in 1999 because of the higher loan rates for soybeans relative to corn (Lin, 1999). Since soybeans are a less fertilizer-intensive crop than corn, 1999 aggregate fertilizer use will likely be less than expected due to the shift in crop mix.

Nutrient Balances—An Alternative Measure of Nutrient Use

Total or per-acre nutrient use is of limited value in determining whether nutrients pose an environmental threat. An alternative measure—nutrient mass or residual balance—calculates the residual nitrogen or phosphorus that may remain in the soil or be lost to the environment. Nutrient mass balances indicate how closely nutrient inputs (such as commercial fertilizer, animal manure, other wastes, irrigation water from nutrient-impacted aquifers, and nutrients provided by previous legume crops) match nutrient outputs (the amount of nutrient taken up by the harvested crop). A positive net mass balance indicates the amount of residual nutrient that may remain in the soil or be lost to the air, carried by water runoff into surface-water systems, or carried by percolating water into ground water. However, residual nitrogen by itself does not necessarily result in water quality problems. For example, warm, moist soil conditions and dry air may volatilize residual nitrogen to the atmosphere, or vegetative buffers may capture residual nitrogen before it reaches water systems. Therefore, nitrate levels in surface and ground water in some areas of the Southeast tend to be low, even though residual nitrogen may be high.

A negative net balance indicates that the amount of nutrient removed from the field through the harvested crop exceeds the amount of nutrient applied, with the difference coming from nutrients stored in the soil or available through precipitation. Continued negative balances mine or deplete nutrients in soil, disrupt the soil ecosystem, and can damage soil productivity.

Residual balances can be computed on acres or fields to assist farmers in making nutrient management decisions. Calculating balances on a wider geographic area may portray the overall potential for nutrient losses and indicate where nutrient management could be improved. Using USDA's Cropping Practice Surveys, nutrient balances are calculated for major crops (see box, "Computing Nutrient Mass Balances"). Balance estimates are categorized as (1) *high* if the nutrient input exceeded the output in the harvested crop by more than 25 percent, (2) *moderate* if nutrient input exceeded output by less that 25 percent, and (3) *negative* if total nutrient input was less than the output. Declining percentages in the high and negative categories and an increasing percentage in the moderate category indicate improvements in nutrient management. No significant change was detected over the 1990-97 period (fig. 4.4.7 and 4.4.8).

Positive residual balances can occur if farmers underestimate available nutrients or over-apply nitrogen--the most critical nutrient--in order to support high crop yields. Other factors are the relatively low marginal cost of applying extra nutrients at the time of initial application in the fall and spring before planting and the extra uncertainty (due to weather delays) of making a timely, second application if needed after planting. High nutrient balances also occur when poor weather or excessive pest damage result in crop yields lower than farmers anticipate and less nutrients are taken up by the harvested crop. Consequently, balances may vary significantly from year to year. Persistent high balances on land vulnerable to leaching can be of particular concern for groundwater quality.

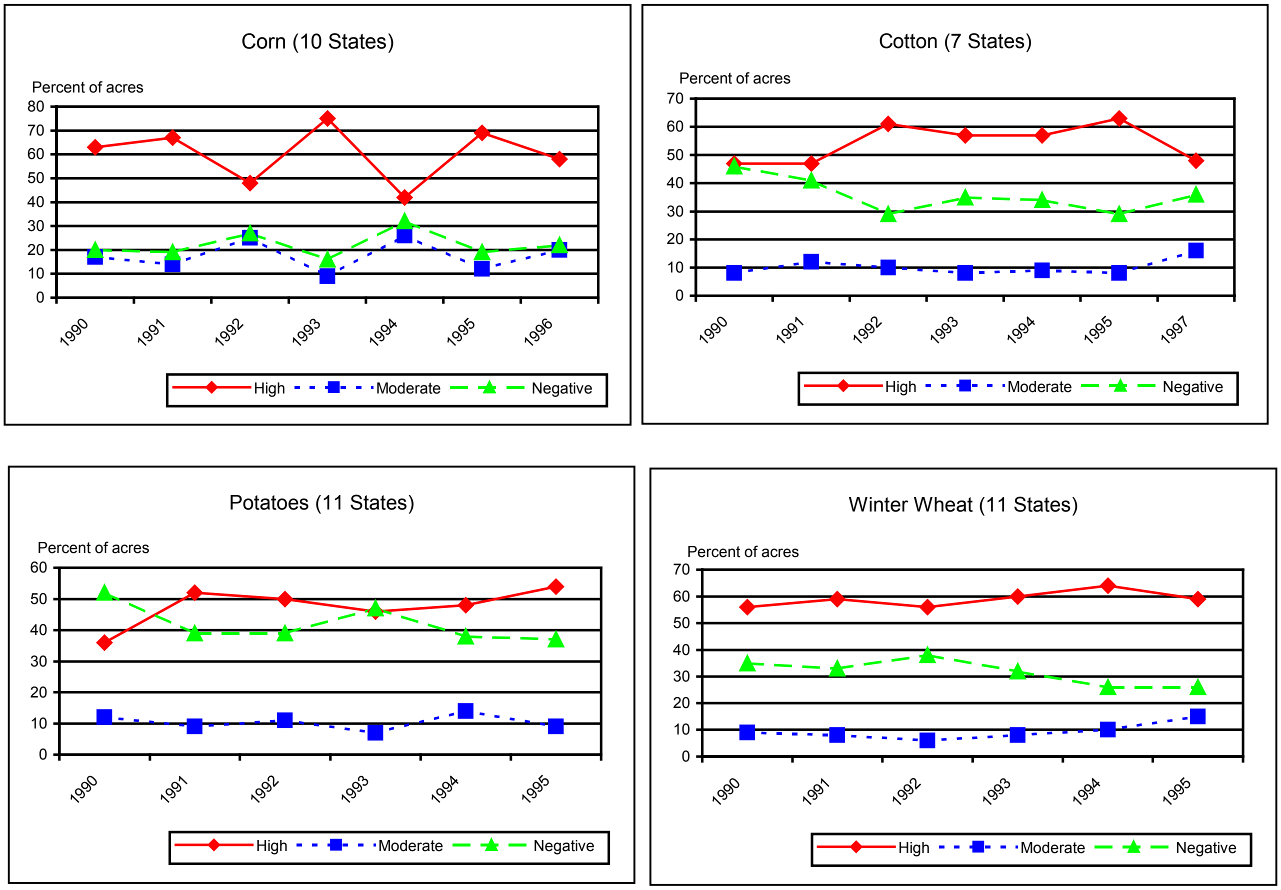
Nitrogen balances

Over half of the corn, cotton, potato, and wheat acres in major producing States had high nitrogen mass balances during 1990-95, suggesting potential nitrogen losses to the environment (fig. 4.4.7, table 4.4.7). Also, in most years, one-fifth or more of these acres had negative nitrogen balances, indicating the mining of nitrogen in the soil to supply crop needs. The percentage of corn acres with high nitrogen balance varies considerably from year to year mainly due to annual variation in yield and crop nutrient uptake. The percentages of cotton and wheat acres with a high nitrogen balance have been increasing, as farmers appear to be applying more nitrogen fertilizer in anticipation of higher crop prices in recent years (NASS, 1996).

Phosphorus balances

High phosphorus balances occurred on 9 percent (soybeans) to 94 percent (potatoes) of major field crops during 1990-97 (fig. 4.4.8, table 4.4.8). In areas with high soil erosion and runoff, the high residual balance of phosphorus could contribute to water quality problems and require improved management. Phosphorus is more stable than nitrogen and more likely to remain in the soil with less loss to the environment unless the soil itself erodes away. Because of this greater stability, and to reduce costs, many farmers apply extra phosphorus one

Figure 4.4.7--Nitrogen mass balances in major producing States, 1990-97
Percentage of acres in high, moderate and negative categories.



year then skip a year or more (USDA, NRCS 1995a). The large percentage of acres with negative mass balances is also evidence of this practice.

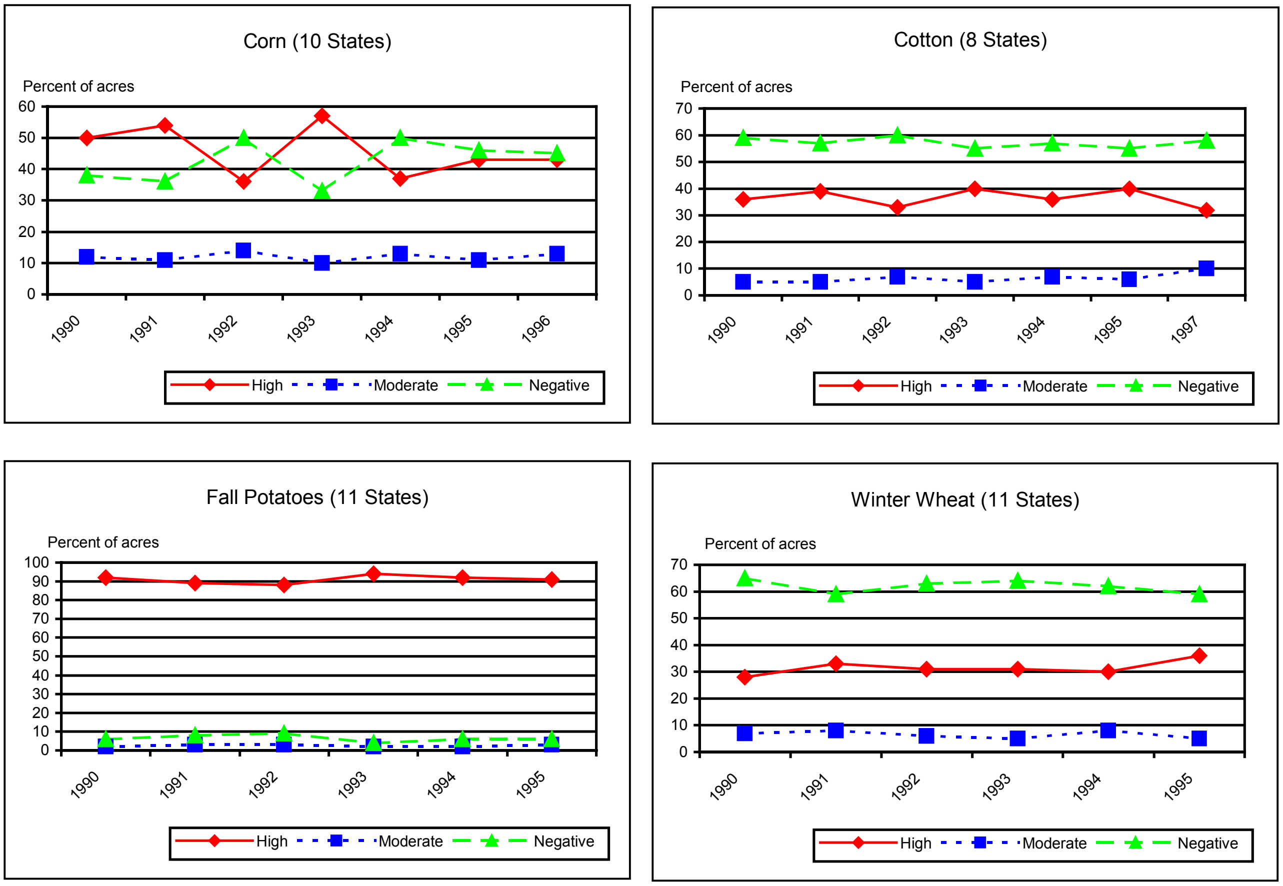
Nutrient Management Practices

Effective nutrient management, which includes assessing nutrient need, timing nutrient application, and placing nutrients close to crop roots, can help reduce nutrient losses to the environment while sustaining long-term productivity and profitability. The efficacy of each practice is strongly influenced by the conditions in each field, the farmer's management knowledge and skill, economic factors, and weather (table 4.4.9).

Assessing nutrient needs

Farmers following conventional practices may apply fertilizer at rates based on optimistic yields and may not account for all sources of nutrients. Improved management requires more information about the nutrients available for crop needs and the use of balances to better assess nutrient need. In addition to computing acre- or field-level mass balances, analyzing plant tissue during the growing season can detect any emerging nitrogen deficiency. Soil tests are readily available for nitrogen, phosphorus, and potassium residuals as well as for pH levels, and micronutrients. Even though such information is essential for improving nutrient management, soil

Figure 4.4.8--Phosphate mass balances in major producing States, 1990-97
Percentage of acres in high, moderate, and negative categories.



tests are an additional expense that many farmers forgo. Nevertheless, soil nitrogen tests and plant analysis can help farmers improve their net farm income (Babcock and Blackmer, 1994; Shortle et al., 1993; Bosch et al., 1994). In particular, soil tests help those farmers who underestimate the nutrient carryover from the previous season to avoid overapplying, thus reducing nitrogen loss and improving their net farm income (Huang et al., 1996). The economic benefit of soil nitrogen testing is greatest in fields where manure was applied and where the previous season was dry (Bosch et al., 1994; Bock et al., 1992; Fuglie and Bosch, 1995). The ideal time to conduct soil nitrogen testing and application is just before plants require nutrients, because nitrogen (as nitrate in the soil) quickly dissipates. However, benefits to the farmer from soil nitrogen tests may disappear if weather conditions prevent farmers from entering fields soon after testing. Because phosphorus is relatively stable in the soil, testing for this nutrient can be conducted any time before fertilization.

In 1997, soil testing ranged from 26 percent of surveyed winter wheat acres to 88 percent of surveyed potato acres (tables 4.4.10-4.4.14). (See appendix tables 4.4.15—4.4.20 hyperlink to .xls file for State data.) The extent of soil testing varies from year to year, but during 1990-97, most soil testing included nitrogen testing, and soil testing for nitrogen increased on potatoes and soybeans. Testing of plant tissues during the growing season indicates any emerging nutrient deficiency, which can then be corrected by an additional nutrient application. With tissue testing, farmers can apply fertilizers at lower rates based on realistic or average yield expectations, then detect and correct (if economical to do so and if conditions permit) any deficiency that might result from above-average growing conditions. In 1997, farmers used tissue testing (primarily for nitrogen) on 67 percent of potato acres (table 4.4.13) and 9 percent of cotton acres (table 4.4.12).

Of the acres soil-tested for nitrogen, farmers typically reported applying the recommended amount for the soil and crop. Whether nitrogen tests help reduce nitrogen fertilizer use depends in part on the nitrogen recommendations provided to farmers by the State Extension Service or fertilizer dealers. However, Schlegel and Havlin (1995) found that the nitrogen rates recommended by typical models were sometimes 30 to 60 percent higher than the profit-maximizing rate. The nutrient content of any manure applied, if known, allows farmers to better determine nutrients needed from other sources. However, manure analysis occurred on only 8 percent of corn and soybean acres receiving manure in 1995, and on only 12 percent of wheat acres (tables 4.4.9-4.4.13). Previous legumes, an additional source of nitrogen, were credited by farmers in determining commercial nutrient needs on only about half of crop acres with previous legumes.

Timing nutrient application
Timing nitrogen applications to the biological needs of a crop leaves less nitrogen available for loss and can reduce total amount applied. Optimum times for fertilizer application vary by crop, texture of soil, climate, and stability of fertilizer (Aldrich, 1984). For example, corn requires most of its nitrogen supply in midsummer. Nitrogen applied either in the fall or early spring is more readily lost to the environment than when applied at or after planting, and farmers often apply a larger amount to make up for the anticipated loss. Splitting nitrogen fertilizer into various applications at and after planting can reduce nitrogen loss by as much as 40 percent without reducing crop yields (Meisinger and Randall, 1991). However, fall and early spring applications are still prevalent, and may be increasing for some crops. Over two-thirds of winter wheat acres and 20-35 percent of corn, soybean, cotton, and potato acres were fertilized with nitrogen in the fall before planting during 1990-97 (table 4.4.10-4.4.14). Another 35-65 percent of soybean, cotton, potato, and corn acres received fertilizer in the spring before planting. The only major field crop with increases in after-planting applications was fall potatoes, and this at the expense of at-planting application. Economic considerations lead many farmers to apply nitrogen before planting during the fall and spring rather than during the growing season (Feinerman et al., 1990; Huang et al., 1994). For example, uncertain weather conditions may shorten the time in which fertilizer can be applied during the growing season, increasing the risk of yield loss from inadequate nitrogen availability. Such risk is magnified for farmers with shorter growing seasons. The opportunity cost of labor and application arrangements may be significantly higher during the late spring and growing season than during the fall. Also, fertilizer pricing patterns (lower in the fall than spring) tend to encourage fall application rather than spring or growing-season application.

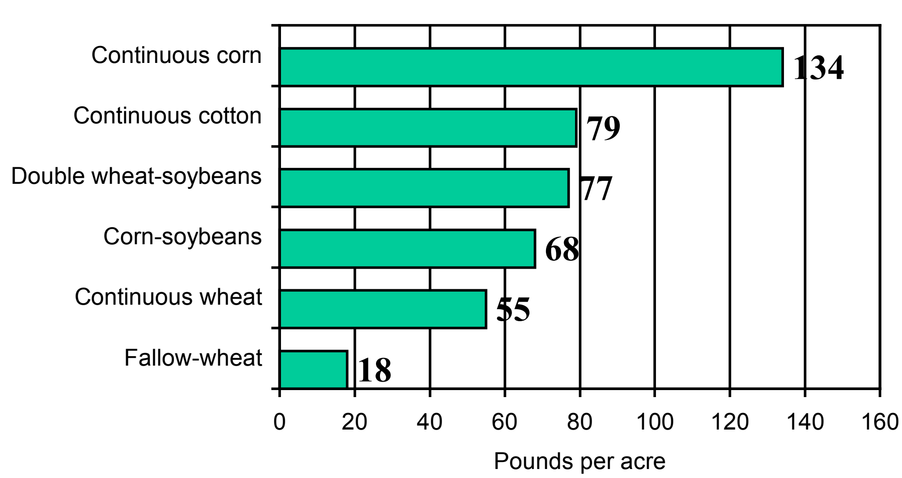
Nutrient placement
For crops surveyed in the Cropping Practices Survey (CPS) and Agricultural Resource Management Study (ARMS) survey, broadcasting was the most common method of applying fertilizers. Broadcasting keeps down the cost of field operations but broadcast nitrogen is more susceptible to loss to the environment. Broadcasting is very widespread among the field crops, ranging from nearly 60 percent of the wheat acres to over 90 percent of the soybean acres (table 4.4.10-4.4.14). In contrast, banded applications— including the use of injection, knifed-in, or side dressing (see Glossary of Nutrient Management Terms)—place nitrogen fertilizer closer to the seed or plant for increased crop uptake (Achorn and Broder, 1991). Banded fertilizer applications on field crops

range from less than 10 percent of the soybean acreage to at least half of all corn acres (table 4.4.10-4.4.14). Banded practices can increase the efficiency of nitrogen fertilizer use. Injection of an ammonia type of nitrogen (such as anhydrous ammonia) into the soil can reduce leaching and volatilization by as much as 35 percent compared with broadcast application (Achorn and Broder, 1991) and can result in a yield increase of as much as 15 percent (Mengel, 1986). The operation cost (variable and fixed) of injection applications is higher than for broadcast applications, but the overall cost (operation and nitrogen fertilizer) is lower.

Nutrient product selection

Nitrogen fertilizers can be ranked according to their chemical stability in the soil—an important factor in determining potential for environmental harm. Ammonium nitrate is the least stable in soil, followed by nitrogen solutions, anhydrous ammonia, urea, and ammonia-based fertilizer with an added nitrification inhibitor (Fertilizer Institute, 1982; Aldrich, 1984). For areas where cropland is vulnerable to leaching (sandy soils), ammonia-based fertilizer can minimize nitrogen loss. For areas where ammonia volatilization is a problem (areas with hot, dry air and moist soils), a nitrate-based fertilizer is preferable. Nitrogen stabilizers or inhibitors (urease inhibitors and nitrification inhibitors) delay the transformation of nitrogen fertilizer from ammonia to nitrate and help match the timing of nitrate supply with peak plant demand (Hoeft, 1984). The potential benefit from nitrification inhibitors is greatest where soils are either poorly or excessively drained, no-till cultivation is used, nitrogen is applied in the fall, crops require a large amount of nitrogen fertilizer, and excessively wet soil conditions prevent the application of nitrogen in the growing season (Hoeft,1984; Nelson and Huber, 1987; Scharf and Alley, 1988). The greatest potential benefit occurs only when nitrification inhibitors are used at or below the optimal nitrogen application rate. A nitrification inhibitor added to anhydrous ammonia is most widely used in corn production. However, ARMS surveys for 1994 and 1996 reveal that corn growers in the Corn Belt are likely to apply more nitrogen fertilizer when a nitrification inhibitor is used. Such a practice can diminish the economic benefit associated with the use of a nitrification inhibitor and can increase the amount of residual nitrogen left on the field for leaching (Huang and Taylor, 1996). During 1990-97, farmers used nitrification inhibitors on acreage ranging from less than 2 percent of winter wheat and potatoes to 11 percent of corn (tables 4.4.10-4.4.14).

Fig. 4.4.9--Average annual nitrogen application rates for common rotations



Crop selection and management

Crops in rotation with a nitrogen-fixing legume crop can reduce nitrogen fertilizer needs. For example, in 1997, nitrogen application on corn in a rotation with soybeans was only 68 pounds per acre, compared with135 pounds on continuous corn (fig. 4.4.9). In addition, crops in rotation reduce soil insect species, improve plant health, and increase nitrogen uptake efficiency. Legume crops at the early stage of growth absorb residual nitrogen in the soil and therefore minimize nitrate leaching. Legume crops, primarily soybeans, were grown the previous year on over 60 percent of the corn acreage during 1997 (table 4.4.10). Even with these benefits, however, crop rotations are often less profitable than monoculture particularly when crop production is subsidized by farm programs. For example, a corn-soybean rotation was shown to be less profitable than continuous corn production under farm programs that included loan rates and deficiency payments (Huang and Lantin, 1993; Huang and Daberkow, 1996). Planting cover crops between crop seasons can prevent the buildup of residual nitrogen. Planting cover crops also can reduce nutrient loss by minimizing soil erosion. Small grain crops and hairy vetch are both nitrogen-scavenging cover crops. Because the economic benefit of planting cover crops is limited for field crops, the practice has not been widely adapted by U.S. farmers. During 1990-95, only 1-4 percent of major field crop acres had previous cover crops (AREI, 1996).

Irrigation management

Improved irrigation practices can help farmers irrigate crops more uniformly and control the quantity of irrigation water in the soil. The quantity of water in the soil affects the nutrient concentration in the soil and the rate of nutrient movement to the root zone (Rhoads, 1991). Too much irrigation water can promote nitrogen leaching, reduce nutrient concentration in the soil, and lower plant uptake. Too little irrigation water can stunt plant growth and reduce crop yield. Irrigation efficiency can be improved, for example, by switching from gravity irrigation to sprinkler irrigation, by scheduling irrigation according to plant need, and by using improved gravity irrigation practices such as a surge system or shorter irrigation runs. The cost of irrigation improvements can be substantial, but the economic benefit from saved irrigation water and increased yield may offset the cost in some areas.

Manure and organic waste management

Manure is a good source of organic matter for the soil. In some cases, it can also be an economical, though limited, source of plant nutrients. The organic matter in soil provides a steady supply of nutrients to the plant, and conditions the soil for the plant to achieve higher yields. However, the nutrients contained in the organic matter can also be lost to the environment through soil erosion. Because of its bulk, the economic benefit of manure is limited by available storage and reasonable transport distance (Bouldin et al., 1984). The benefit of manure varies by region; application of manure in corn production is profitable for farmers in Iowa (Chase et al., 1991). Transfer of poultry litter from the litter-surplus areas to litter-deficiency areas in Virginia is economically viable (Bosch and Napit, 1992; Govindasamy and Cochran, 1995). Most feedgrain and confined-livestock farms can benefit from manure use for crop production (Gollehon and Letson, 1996). Managing nutrients in manure for crop use requires testing because of its variable nutrient content, planning its efficient use in crop production through, for example a whole-farm nutrient management plan, and storing it to minimize nutrient loss until the time of the crops' greatest need (USDA, NRCS 1992). During 1990-97, manure application to major field crops ranged from 2-3 percent of winter wheat to 13-18 percent of corn acres (tables 4.4.10-4.4.14).

Improving Nutrient Management

Federal and State governments play an important role in helping reduce agricultural nonpoint pollution of water resources (EPA, 1991). EPA establishes minimum water quality standards and regulates animal waste discharges from large confined livestock operations under the Clean Water Act. States can regulate input use and land use, land acquisition, and easements to preserve areas deemed important for protecting water resources. (For more on water quality programs, see Chapter 6.4)

Society, acting through government, can (1) adjust the anticipated costs or benefits of certain production practices through education, technical assistance, and input taxes or by offering subsidies to farmers to adopt certain practices; (2) restrict or regulate certain production practices, such as the use of highly leachable fertilizers in vulnerable areas; (3) help create markets for animal and poultry manures; and (4) invest in research and development to find production practices that are less environmentally damaging. Approaches 1 and 3 are economic or incentive-based approaches and are often preferred because they allow maximum flexibility in meeting environmental goals at minimum cost.

USDA prefers voluntary, incentive approaches to deal with agricultural water pollution. This preference is based on the inherent difficulty in regulating nonpoint sources of pollution, and on the belief that when educated about the problems and provided technical and financial assistance, farmers will make improvements in production practices to achieve conservation and environmental goals. In passing the Federal Agriculture Improvement and Reform Act of 1996, Congress reaffirmed its preference for dealing with agricultural resource problems using voluntary approaches.

Adjusting the anticipated costs or benefits of production practices

USDA provides educational, technical, and financial assistance to encourage adoption of nutrient management and other less polluting practices. Education helps farmers understand the need for improved practices and demonstrates the practices in operation while technical assistance helps install and implement the practices. Financial assistance can help offset the added cost or risk associated with farmer's adopting some practices (see box, "Efficiency of Financial Incentive Programs"). Also, providing insurance to farmers who adopt nutrient management practices or technologies that may have some yield risks associated with their use, has also been proposed (ACIC, 1999)

The Federal Agriculture Improvement and Reform Act of 1996 established the Environmental Quality Incentives Program (EQIP) in USDA to replace most previous financial assistance programs and to better target assistance to areas most needing actions to improve or preserve environmental quality. Half of EQIP funding is to be directed to conservation practices relating to livestock production, including waste and nutrient management improvement. The program may emphasize extensive or management-type practices that are more cost effective than intensive structural-type measures. Such direction would favor improved nutrient management (USDA, NRCS, May 2000).

The relative costs of nutrient management practices can be adjusted through input or discharge taxes, such as a tax on nitrogen applied in excess of nitrogen removed (Huang and LeBlanc, 1994). In effect, the residual nitrogen tax is an effluent tax, which induces farmers to adopt improved practices to reduce the residual. Also, it can generate revenue to support development and promotion of improved practices. A nitrogen fertilizer and pesticide use tax in Iowa generates revenue for research and extension activities in water quality improvement. More than $1 million of tax revenue is generated annually and used to develop and promote alternative farming practices to reduce nitrate leaching (Leopard Center, May 2000).

Regulatory approaches
Regulatory approaches can impose a lower cost on farmers than do fertilizer or discharge taxes (Huang and Lantin, 1993) and can be a least-cost approach for society when unseasonal weather occurs (Baumol and Oates, 1988). The Clean Water Act is an example of a program that that could be applied to limit farm nutrient use in the interests of the environment. Imposing restrictions on nitrogen fertilizer use can affect farmers differently, depending on current production practices (Huang, Shank, and Hewitt, 1996).

Several States have established a regulatory agency to control nitrate leaching. Currently, several States require that livestock farms have comprehensive nutrient management plans that account for all sources of nutrients and that match nutrient application and availability to crop need (USDA, NRCS 1995b). In 1969, Nebraska created 24 multipurpose Natural Resources Districts (NRD's) and gave them authority to levy a local property tax to fund a wide variety of services to protect Nebraska's natural resources (Nebraska Association of Resources Districts, 1990). One district, the Central Platte NRD, suffers a high level of nitrate-nitrogen in the ground water (CPNRD, 1993, 1995). Three phases of regulation were established, depending on the groundwater nitrogen level, potential impact on municipal water supply, and nitrogen levels in the zone between crop roots and ground water. Restrictions on fertilizer use increase with each phase. Nearly all farm operators have complied, completing reports on nitrogen use, taking necessary soil and water tests, and cutting back their use of commercial nitrogen fertilizer. Since the regulatory program was established in 1987, nitrate concentrations in the ground water in some areas in the Central Platte Basin have stabilized (CPNRD, 1995). Prior to 1987, groundwater nitrate levels in parts of the CPNRD had increased at a rate of about 0.5 ppm (parts per million) per year, reaching over 19 ppm by 1987. Since 1987, groundwater nitrate levels declined in most years and, by 1997, were about 17 ppm (CPNRD, 1998).

As animal operations become larger, more States are looking at ways of protecting the environment from animal waste (U.S. EPA, May, 2000). Large, confined-animal operations can present major water quality problems, and operations greater than 1,000 animal units are subject to point-source permits under the Clean Water Act. Recently, these permits have begun to address both storage of manure on the site, and land disposal. In 1993, Pennsylvania became the first State to pass a comprehensive nutrient management law aimed at concentrated animal operations. Animal operations with over two animal units per acre of land available for spreading must have a farm-level nutrient management plan that demonstrates that waste is being safely collected and disposed of (Beagle and Lanyon, 1994). Recently, the States of Maryland and Virginia enacted legislation to require poultry farms to establish nutrient management plans based on manure application rates not to exceed crop phosphorus requirements. Land-use laws that affect agriculture are being used by municipalities, counties, and other local governments. Zoning ordinances are used in many areas, especially around the rural-urban fringe, to regulate the location of confined-animal operations (U.S. EPA, May, 2000).

Establishing markets for animal wastes
Another way to improve nutrient management is to facilitate the transfer of manure from farms that have excess to those that need additional nutrients. This can be done by establishing a market for trading manure products and for gathering and exchanging technical information. A market for poultry litter was established in Arkansas,

the largest broiler-producing State. In 1991, Winrock International began a project aimed at transferring excess litter in the western part of the State to rice farmers in eastern Arkansas as a natural soil amendment to improve the fertility of zero-grade rice fields where topsoil has been scraped off. Rice straw, in turn, is an important bedding material for poultry houses in western Arkansas. A poultry litter hotline was launched in 1993 to link prospective buyers and sellers. Also, Tyson Foods, the largest poultry processor, approved the same trucks delivering clean bedding from the Delta area to its contracted poultry farms to back-haul litter from the poultry farms to the Delta rice farms, reducing the cost of transporting litter. An average of 30 litter buyers and sellers were listed on the hotline in 1995, with double that number in December and January. The litter market increased incomes of both poultry farmers and rice farmers, while mitigating water quality problems in western Arkansas (Winrock International, 1995).

Research, development, and demonstration

The Federal Government also plays a major role in research, development, and demonstration of improved nutrient management. During 1991-94, USDA funded various Hydrologic Unit Area (HUA) and Demonstration Projects (DP), which helped farmers to implement improved nutrient management over a wide range of geographic settings, agricultural types, and water quality problems across the Nation. Case studies of eight DP's and eight HUA's found reductions in annual nitrogen application because of the improved nutrient management practices (USDA, NRCS, 1995a). Also, USDA, in cooperation with the U.S. Geological Survey, U.S. Environmental Protection Agency, and State experiment stations, established various Management Systems Evaluation Areas (MESA's) to better understand the linkages between farming practices and water quality in the Midwest (ARS, 1993). Nutrient management is the major focus of these projects, which include monitoring activities, modification of farming systems, alternative and new farming practices, site-specific management, nitrogen testing, and socioeconomic studies of farming systems.

New technology to manage nutrients: precision farming

Innovations in the computer, telecommunications, and satellite industries during the last decade have made spatial and temporal management of nutrients, and other inputs, within fields technically feasible. The application of these information technologies, known as precision farming or site-specific farming, enables producers to monitor and differentially manage small areas of a field that have similar soil or plant characteristics. Components of a precision farming system typically include: intensively testing soils or plant tissues within a field; equipment for locating position within a field via the Global Positioning System (GPS); a yield monitor; a computer to store and manipulate spatial data using some form of Geographic Information System (GIS) software; and a variable-rate applicator. More involved systems may also use remote sensing from satellite, aerial, or near-ground imaging platforms during the growing season to detect and treat areas of a field that may be experiencing nutrient stress. For example, recent research on corn indicates that remote sensing can successfully detect nitrogen stress (Bausch, Duke, and Hermann, 1997).

A preliminary estimate of additional fixed and variable costs of precision farming for corn is about $7-$8 per acre (Lowenberg-DeBoer and Swinton, 1995). Precision farming has the potential to improve net farm income by: (1) identifying places in a field where additional nutrient use will increase yield, and thus farm income, by more than the added cost; and (2) identifying places where reduced input use will reduce costs while maintaining yield. Precision farming also has the potential to reduce off-site transport of agricultural chemicals with surface runoff, subsurface drainage, and leaching (Baker and others, 1997; Watkins, Lu, and Huang, 1998). Two years of Kansas field data indicate less total nitrogen fertilizer use with precision farming than with

conventional nitrogen management (Snyder and others, 1997). USDA surveys indicate that about 10 percent of corn farms in the United States are using some aspect of precision farming, primarily for nutrient management (Daberkow and McBride, 1998).
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Glossary of Fertilizer Terms

Ammonium nitrate--A prilled or granulated product containing not less than 33 percent nitrogen, half in the ammonium form and half in the nitrate form.

Ammonium sulfate--Soluble in water and contains 21 percent nitrogen and 24 percent sulphur. It is usually made by treating bauxite with sulfuric acid. It is applied to western soils to make them less alkaline.

Anhydrous ammonia--A colorless, pungent gas containing 82.25 percent nitrogen and 17.75 percent hydrogen, which can be liquefied and transported at normal temperatures in high-pressure cylinder tanks, and injected under pressure into the soil or mixed with irrigation water.

Available nutrients--That part of fertilizer supplied to the plant that can be taken up by the plant.

Blended fertilizer--A mixture of two or more fertilizer materials.

Diammonium phosphate (DAP)--A product made from wet process phosphoric acid and ammonia containing 18 percent nitrogen and 46 percent phosphate.

Economically recoverable manure--The excreta of animals (dung and urine) mixed with straw or other materials that can be economically recovered and used as a fertilizer.

Guano--Partially decomposed excrements of birds, bats, seals, or other animals.

Inorganic fertilizers--Fertilizer materials in which carbon is not an essential component of its basic chemical structure.

Lime--A soil conditioner consisting essentially of calcium carbonate, calcium oxide, calcium hydroxide, magnesium carbonate, magnesium oxide, or a combination of these capable of neutralizing soil acidity.

Micronutrients--Boron, chlorine, cobalt, copper, iron, manganese, molybdenum, sodium, and zinc are needed only in small amounts. They contribute to cell division, photosynthesis, fruit formation, carbohydrate and water metabolism, chlorophyll formation, protein synthesis, and seed development.

Mixed fertilizers--Two or more fertilizer materials mixed or granulated together into individual pellets.

Muriate of potash (potassium chloride)--A potash salt of hydrochloric acid (muriatic acid) containing 60-62 percent soluble potash.

Natural organic fertilizers--Materials derived from either plant or animal products containing one or more elements (other than carbon, hydrogen, and oxygen) essential for plant growth.

Nitrogen solutions--Solutions of nitrogen fertilizer chemicals in water. Urea ammonium nitrate (UAN) solutions are made from a mixture of urea and ammonium nitrate and contain 28-32 percent nitrogen.

Primary Nutrients--

Nitrogen (N) is an essential element in the production of food protein by plants and in the conversion of carbon dioxide in the air and water into carbohydrates through photosynthesis. It also is essential for vigorous plant growth and for obtaining high crop yields. Principal forms of nitrogen fertilizer are anhydrous ammonia, urea, ammonium nitrate, ammonium sulfate, and nitrogen solutions.

Phosphate (P_20_5), the oxide form of phosphorus (P) is vital to plant growth playing a key role in photosynthesis, respiration, energy storage and transfer, cell division, cell enlargement, genetic coding, and many other plant processes. An adequate level of phosphate provides rapid, extensive growth of young plant roots. Principal forms of phosphate fertilizer are normal and concentrated superphosphate, and monoammonium and diammonium phosphate.

Potash (K_20), the oxide form of potassium (K) activates many enzyme systems in the plant and helps the plant use water more efficiently with less loss. It is essential for varied process-photosynthesis rates, product formation, winter hardness, and disease resistance. It stops stalks from lodging, preventing a decrease in crop yields. Principal forms of potash fertilizer are potassium chloride, potassium sulfate, and potassium nitrate.

Secondary Nutrients--Calcium, magnesium, and sulfur are essential to plant growth in lesser quantity than nitrogen, phosphate, and potash but in greater quantity than micronutrients.

Sewage sludge--Solids removed from sewage by screening, sedimentation, chemical precipitation, or bacterial digestion.

Sodium nitrate--The sodium salt of nitric acid containing not less than 16 percent nitrate nitrogen and 26 percent sodium.

Superphosphate--Products obtained when rock phosphate is treated with either sulfuric acid or phosphoric acid or a mixture of these acids. Normal superphosphate contains up to 22 percent phosphoric acid (P_20_5). Enriched superphosphate contains more than 22 percent but less than 40 percent phosphoric acid. Concentrated or triple superphosphate contains more than 40 percent phosphoric acid.

Urea--A white crystalline or granular solid synthesized from ammonia and carbon dioxide under high temperature and pressure and containing not less than 45 percent nitrogen.

Glossary of Nutrient Management Terms

Animal units-- An animal unit is commonly defined to mean one beef head, 0.7 dairy cows, 2.5 hogs, 55 turkeys, or 100 chickens.
Broadcast applications—Fertilizer broadcast in either granule or liquid form on all field surfaces. Most ground broadcast equipment for granular fertilizer uses one or two disks to broadcast fertilizer in 12- to 15-meter swaths. Nitrogen solutions are broadcast using various types of spray nozzles. Aircraft is used for aerial application.
Chemigation—Nitrogen solutions applied through irrigation water.
Cover crops—Planting a cover crop after harvest to take up residual nitrogen and therefore minimize leaching.
Credits for other nutrient sources—Other sources of nutrients include nitrogen from legumes planted in the previous crop, nitrate in irrigation water and precipitation, and nitrogen, phosphorus, and potassium in animal manure and other (such as municipal) wastes.
Crop residues—Incorporation of crop residual into the soil helps immobilize residual nitrogen.
Crop rotation—A multi-year crop sequence, for example, non-legume crops then legume crops.
Incorporation—Fertilizer is covered or mixed with soil through tillage.
Injection/knifed-in application—Nitrogen fertilizer is injected or knifed-in usually 12-24 cm below the soil surface. It can also be incorporated into the soil by tillage. High-pressure liquid nitrogen such as anhydrous ammonia is the most common form of nitrogen injected into the soil. Nitrogen solutions in low-pressure liquid form are also injected into the soil.
Irrigation practices—Use of improved gravity irrigation, a sprinkler irrigation system, soil moisture testing, or an irrigation schedule to tailor irrigation to crop needs and to apply irrigation water uniformly.
Nitrification inhibitors—Chemical compounds that can be added to the ammonia fertilizers to slow the conversion of ammonium nitrogen to nitrate nitrogen, which is susceptible to leaching. N-inhibitors can be used with manure and other forms of organic nitrogen fertilizer.
Nutrient recommendations—The rate of the plant nutrient to be applied is the difference between the amount of nutrients required by the crop based on a realistic yield goal and the amount of the nutrients already available for plant uptake, as determined by soil nutrient tests and nutrient credits for other sources. Many land grant universities provide nutrient recommendations based on information obtained from long-term field trials.
Plant tissue analysis—A test that uses chlorophyll (or greenness) sensing to detect nitrogen deficiency during the plant's growing period. Correction of any nitrogen deficiency is then made through chemigation or other foliar application (Sander et al., 1994).
Precision (prescription or site-specific) farming—An information and technology-based crop management system to identify, analyze, and manage spatial and temporal variability within fields.
Side-dressing or banded application—Granule or liquid nitrogen fertilizer is placed to one side of the plant or placed every other row at planting or during the growing season.
Slow-release nitrogen fertilizer—Fertilizer coated with chemicals that can retard release of nitrogen from applied fertilizer and prolong the supply of nitrogen for plant uptake.
Soil test—Chemical analysis of soil composition to estimate the availability of plant nutrients, pH, soil electrical conductivity, organic matter, or other soil properties. Soil test results often include nutrient recommendations.
Split applications—Total fertilizer for crop need is split into several applications during the growth of the crop.
Urease inhibitors—Chemical compounds that can be added to urea to slow the conversion of urea to ammonium and therefore to slow nitrate leaching.

Computing Nutrient Mass (Residual) Balances

Per-acre, field-level data from the Cropping Practices Survey were used to estimate nutrient balances in pounds per acre for each nutrient on each sample field, using the following procedure:

NB = CF + L + NPK - H - (PR-CR)

Where:
NB = Nutrient Balance
CF = Nutrients from Commerical Fertilizer in pounds applied per acre
L = Nitrogen from previous **L**egume crops. If the previous legume crop was soybeans, 1 pound of nitrogen credit was assumed for each bushel of soybeans harvested. If the crop in the previous year was first-year alfalfa, the nitrogen credit per acre was 50 percent of the nitrogen in harvested alfalfa. If the crop was second-year alfalfa, the nitrogen credit was 75 percent of the nitrogen in harvested alfalfa (Meisinger and Randall, 1991).
NPK = **N**itrogen, **P**hosphorus, and potassium (**K**) credits for applied manure for 1990-94 were estimated from two data sources: USDA's Area Study Survey (Alabama, Florida, Georgia, Idaho, Illinois, Indiana, Iowa, Maryland, Nebraska, and Minnesota) and the 1992 Agricultural Census (other States). The estimation procedures used were those developed by Van Dyne and Gilberson (1974) and by Gollehon and Letson (1996). The NPK credits for 1995 were estimated directly from survey data. The estimation procedures were from the *Agricultural Waste Management Field Handbook* (USDA, NRCS, 1992).
H = Nutrients assumed per unit of crop **H**arvested were 0.9 pound of nitrogen and 0.35 pound of phosphorus for each bushel of corn, 1.25 pounds of nitrogen and 0.625 pound of phosphorus for each bushel of wheat, and 0.05 pound of nitrogen and 0.013 pound of phosphorus for each pound of cotton lint and seed (Fertilizer Institute, 1982; Meisinger, 1984).
PR = Nutrients from **P**revious crop **R**esidue.
CR = Nutrients in **C**urrent crop **R**esidue remaining on the field.

Nutrients from plant residues are assumed to remain on the field and be equal in nutrient value at beginning and end of season. State and crop-level estimates were developed by extrapolating and aggregating field-level data.

Efficiency of Financial Incentive Programs

A study of USDA's Water Quality Incentives Projects (WQIP)—which provided producers with financial assistance to make changes in nutrient and other management systems to restore or enhance water resources impaired by agricultural sources of pollution—found that practices requiring minor, inexpensive changes in existing farm operations tended to be adopted more frequently than those involving more expensive changes (Feather and Cooper, 1995). Belief that adoption will increase profits was found to be the most common reason for adoption: familiarity with the improved management practice was found to be the second most important reason for adoption followed by beliefs that the practice improves onfarm water quality.

To determine the sensitivity of adoption to WQIP incentive payment levels, non-adopting producers were asked if they would adopt improved management practices given various hypothetical incentive payments. In many cases, the incentive payments required to achieve a 50-percent adoption rate were much greater than the actual payments for these practices. Practices requiring larger incentive payments typically involved expensive changes in the farm operation.

The results of this study have several policy implications.

- First, the efficiency of financial incentive programs may be increased by targeting practices providing the largest reduction in pollution per dollar of incentive payment.
- Second, educational programs seem to be most successful with practices that involve small, inexpensive changes in the operation and are profitable to the producer. Water-quality benefits influence adoption decisions, but profitability is the most important factor. Thus, educational programs without substantial incentive payments may have limited success encouraging practices involving large expenditures.
- Third, both educational and financial incentive programs should recognize that adoption patterns vary by geographical areas. Instead of implementing a uniform program across the nation, region-specific programs may be more effective.
- Lastly, efforts that use both educational and financial incentives require fewer resources and may be more successful than attempts to implement each program separately. A financial incentive program, for example, could be combined with an educational program targeting different practices. These two programs could be combined by requiring producers to enroll in the educational program in order to receive incentive or cost-sharing payments.

Recent ERS Research on Nutrient Management

Economics of Water Quality Protection from Nonpoint Sources: Theory and Practice. AER-782, December 1999 (Marc Ribaudo, Rick Horan, and Mark Smith). Water quality is a major environmental issue. Pollution from nonpoint sources is the single largest remaining source of water quality impairments in the United States. Agriculture is a major source of several nonpoint-source pollutants, including nutrients, sediment, pesticides, and salts. Agricultural nonpoint pollution reduction policies can be designed to induce producers to change their production practices in ways that improve the environmental and related economic consequences of production. The information necessary to design economically efficient pollution control policies is almost always lacking. Instead, policies can be designed to achieve specific environmental or other similarly related goals at least cost, given transaction costs and any other political, legal, or informational constraints that may exist. This report outlines the economic characteristics of five instruments that can be used to reduce agricultural nonpoint source pollution (economic incentives, standards, education, liability, and research) and discusses empirical research related to the use of these instruments.

"On-farm Costs of Reducing Residual Nitrogen on Cropland Vulnerable to Nitrate Leaching," *Review of Agricultural Economics,* Vol. 18, No. 4, Sept. 1996 (Wen-yuan Huang, David Shank, and Tracy Irwin Hewitt). A farm-level dynamic model considering nitrogen carryover effects was used to analyze the costs to a farmer of complying with a restriction on nitrogen fertilizer use on cropland vulnerable to nitrate leaching. While the theoretical results were indeterminate, empirical results from an Iowa case study indicated that a fertilizer use restriction on cropland highly vulnerable to leaching will have a smaller compliance cost than on cropland with a moderate leaching potential.

"Incentive Payments to Encourage Farmer Adoption of Water Quality Protection Practices," *American Journal of Agricultural Economics*, Vol. 78, No.1, Feb. 1996 (Joseph C. Cooper and Russ W. Keim). This paper uses both a bivariate probit with sample selection model and a double-hurdle model to predict the impacts of different incentive payments on farmer adoption of integrated pest management, legume crediting, manure tests, split applications of nitrogen, and soil moisture testing. The results can be used to aid decisions on how to allocate program budgets among the preferred production practices.

"Economic and Environmental Implications of Soil Nitrogen Testing: A Switching-Regression Analysis," *American Journal of Agricultural Economics*, Vol. 77, No. 4, Nov. 1995 (Keith O. Fuglie and Darrell J. Bosch). A simultaneous equations, or “switching-regression,” model is developed to assess the impact of soil nitrogen (N) testing on N use, crop yields, and net returns in corn growing areas of Nebraska. The results indicate that when there is uncertainty about the quantity of available carryover N, testing for N enables farmers to reduce fertilizer use without affecting crop yields. However, the value of information from N tests depends critically on cropping history and soil characteristics.

"The Role of Planting Flexibility and the Acreage Reduction Program (ARP) in Encouraging Sustainable Agricultural Practices," *Journal of Sustainable Agriculture*, Vol. 7, No. 1, Sept. 1995 (Wen-yuan Huang and Stan G. Daberkow). This article examines the impact of increasing planting flexibility (P) on program participation, farm in-come, crop diversity, and government payments. For a representative western Corn Belt farm, increasing P to more than 63 percent with zero ARP would result in farmers being better off in switching from continuous corn to a corn-soybean rotation. However, increasing the P and reducing the ARP may sacrifice some environmental benefits.

Voluntary Incentives for Reducing Agricultural Nonpoint Source Water Pollution. AIB-716, May 1995 (Peter M. Feather and Joseph Cooper). This report examines the success of existing incentive programs in achieving adoption of manure crediting, legume crediting, split N application, irrigation scheduling, and deep soil nitrate testing. Results indicate large incentive payments may be necessary to achieve high adoption levels, and adoption rates differ both across practices and across geographic areas. Programs involving cost-sharing and incentive payments could be more successful if incentives were altered to account for these differences.
continued

Recent ERS Research on Nutrient Management (continued)

"Voluntary Versus Mandatory Agricultural Policies to Protect Water Quality: Adoption of Nitrogen Testing in Nebraska," *Review of Agricultural Economics*, Vol 17, No. 1 Jan. 1995. (Bosch, D. L., Z. L. Cook, and K.O. Fuglie). This article evaluates the effectiveness of regulation versus a combination of voluntary incentive approaches for increasing Nebraska farmers' use of soil and/or tissue testing on the fields planted to corn. The results indicate that while regulation leads to higher levels of N test adoption, it does not have an "educational" effect on adopters. Educational programs may be needed to complement regulations to ensure that farmers change their behavior to achieve the goals of water quality protection programs .

"Market-Based Incentives for Addressing Non-point Water Quality Problems: A Residual Nitrogen Tax Approach," *Review of Agricultural Economics*, Vol. 16, No. 4, Sept. 1994 (Wen-yuan Huang and Michael LeBlanc). This study analyzes the implications of a tax scheme that would penalize farmers for applying nitrogen in excess of a crop's nitrogen uptake and reward them for growing crops that capture and utilize residual soil nitrogen. Corn production is used to illustrate the differential impacts of residual nitrogen tax on farm income in Corn Belt States.

***An Economic Analysis of Agricultural Practices Related to Water Quality: the Ontario (Oregon) Hydrologic Unit Area.* ERS Staff Report No. AGES-9418. June 1994 (C.S. Kim, Ronald Fleming, Richard M. Adams, Marshall English, and C. Sandretto). This report evaluates the effects of adopting Best Management Practices (BMP's) on groundwater quality in the Ontario (Oregon) area by incorporating time lags associated with nitrate leaching and groundwater flow. Results indicate that a Federal drinking water standard of no more 10 ppm nitrate in groundwater may be accomplished in 12 years by adopting improved irrigation systems such as auto-cutback systems or solid-set sprinkler systems. However, to meet the strict Oregon drinking water standard of 7 ppm, farmers would have to adopt improved irrigation systems as well as nutrient management systems, such as side-dressing, and abandon fall fertilization.**

"The Role of Information in the Adoption of Best Management Practices for Water Quality Improvement." *Agricultural Economics*, No. 11 April 1994. (Peter M. Feather and Gregory S. Amacher). This paper tests the hypothesis that a lack of producer information regarding both the profitability and the environmental benefits of adopting improved practices may be a reason why widespread adoption of these practices has not occurred. A two-stage adoption model is specified and estimated using data from a survey of producers. The results indicate that producer perceptions play an important role in decision to adopt. Changing these perceptions by means of an educational program may be a reasonable alternative to financial incentives.

***Timing Nitrogen Fertilizer Applications to Improve Water Quality*. ERS Staff Report No. AGES-9407, February 1994 (Wen-yuan Huang, Noel D. Uri, and LeRoy Hansen). Analytical models are developed to determine the necessary conditions for the optimal timing of nitrogen fertilizer application. The empirical results explain various observed timings of nitrogen fertilizer application to cotton in Mississippi, and provide an estimate of a farmer's cost in complying with a restriction on the timing of nitrogen fertilizer application.**

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Table 4.4.1--U.S. commercial fertilizer use, 1960-98[1]

Year June 30	Total materials[2]	Primary nutient use			
		Nitrogen (N)	Phos-phate (P_2O_5	Potash (K_2O)	Total[3]
		Million tons			
1960	24.9	2.7	2.6	2.2	7.5
1961	25.6	3.0	2.6	2.2	7.8
1962	26.6	3.4	2.8	2.3	8.4
1963	28.8	3.9	3.1	2.5	9.5
1964	30.7	4.4	3.4	2.7	10.5
1965	31.8	4.6	3.5	2.8	10.9
1966	34.5	5.3	3.9	3.2	12.4
1967	37.1	6.0	4.3	3.6	14.0
1968	38.7	6.8	4.4	3.8	15.0
1969	38.9	6.9	4.7	3.9	15.5
1970	39.6	7.5	4.6	4.0	16.1
1971	41.1	8.1	4.8	4.2	17.2
1972	41.2	8.0	4.9	4.3	17.2
1973	43.3	8.3	5.1	4.6	18.0
1974	47.1	9.2	5.1	5.1	19.3
1975	42.5	8.6	4.5	4.4	17.6
1976	49.2	10.4	5.2	5.2	20.8
1977	51.6	10.6	5.6	5.8	22.1
1978	47.5	10.0	5.1	5.5	20.6
1979	51.5	10.7	5.6	6.2	22.6
1980	52.8	11.4	5.4	6.2	23.1
1981	54.0	11.9	5.4	6.3	23.7
1982	48.7	11.0	4.8	5.6	21.4
1983	41.8	9.1	4.1	4.8	18.1
1984	50.1	11.1	4.9	5.8	21.8
1985	49.1	11.5	4.7	5.6	21.7
1986	44.1	10.4	4.2	5.1	19.7
1987	43.0	10.2	4.0	4.8	19.1
1988	44.5	10.5	4.1	5.0	19.6
1989	44.9	10.6	4.1	4.8	19.6
1990	47.7	11.1	4.3	5.2	20.6
1991	47.3	11.3	4.2	5.0	20.5
1992	48.8	11.4	4.2	5.0	20.7
1993	49.2	11.4	4.4	5.1	20.9
1994	52.3	12.6	4.5	5.3	22.4
1995	50.7	11.7	4.4	5.1	21.3
1996	53.6	12.3	4.5	5.3	22.1
1997	55.0	12.4	4.6	5.4	22.4
1998	55.0	12.3	4.6	5.3	22.3

[1]Includes Puerto Rico. Detailed State data shown in (USDA, 1997). Fertilizer statistics used in this report include commercial fertilizers purchased for use on farms such as chemical fertilizers and natural processed and dried organic materials. Purchased natural processed and dried organic materials historically have represented about 1 percent of total nutrient use.
[2] Includes secondary and micronutrients. Most of the difference between total primary nutrient tons and total fertilizer materials is carrier or filler materials.
[3]Totals may not add due to rounding.
Source: Fertilizer use estimates for 1960-84 are from USDA; *Commercial Fertilizers,* 1985 and earlier issues; those for 1985-94 are from Tennessee Valley Authority (TVA), *Commercial Fertilizers*, 1994 and earlier issues; and those for 1995-97 are from The Association of American Plant Food Control Officials, *Commercial Fertilizers, 1995-98*.

Table 4.4.2--Regional commercial nutrient use for year ending June 30, 1989-98[1]

Region	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
					1,000 tons					
Nitrogen:										
Northeast	313	306	299	328	350	376	349	334	354	351
Lake States	1,011	1,134	1,128	1,119	1,073	1,186	1,108	1,108	1,236	1,172
Corn Belt	3,041	3,215	3,280	3,279	3,003	3,562	3,228	3,354	3,243	3,220
Northern Plains	1,680	1,751	1,978	1,954	2,090	2,319	2,133	2,219	2,373	2,317
Appalachia	613	667	662	718	705	720	694	752	741	763
Southeast	643	670	627	655	682	701	640	694	660	635
Delta States	560	643	609	674	615	663	630	718	607	752
Southern Plains	1,217	1,117	1,223	1,192	1,235	1,377	1,208	1,186	1,258	1,282
Mountain	626	642	628	666	744	775	765	806	862	867
Pacific	916	921	838	849	886	953	953	1,122	1,010	938
U.S. total[2]	10,619	11,065	11,273	11,432	11,382	12,633	11,709	12,294	12,344	12,297
Phosphate:										
Northeast	188	197	188	208	211	232	203	183	184	171
Lake States	477	508	479	468	474	465	461	474	537	487
Corn Belt	1,254	1,334	1,262	1,269	1,312	1,317	1,257	1,340	1,304	1,275
Northern Plains	522	550	583	577	646	649	617	626	713	772
Appalachia	361	381	384	409	410	412	399	396	413	409
Southeast	297	308	281	295	314	297	313	332	318	328
Delta States	154	177	154	180	172	192	197	213	198	221
Southern Plains	342	315	334	288	340	363	341	313	319	330
Mountain	253	279	255	270	296	298	300	312	306	338
Pacific	270	289	274	248	257	291	326	335	316	290
U.S. total[2]	4,119	4,339	4,195	4,212	4,431	4,517	4,412	4,523	4,609	4,621
Potash:										
Northeast	232	261	262	267	262	299	280	230	234	228
Lake States	852	941	832	809	779	781	760	776	866	848
Corn Belt	1,974	2,132	2,044	1,987	2,034	2,133	1,996	2,098	2,153	2,074
Northern Plains	129	133	134	123	134	123	124	123	147	168
Appalachia	506	538	539	584	575	576	574	592	624	634
Southeast	558	559	517	556	581	535	563	587	563	564
Delta States	212	240	229	280	288	302	336	351	323	316
Southern Plains	149	143	150	146	168	191	168	172	178	172
Mountain	53	65	80	55	80	68	79	79	80	91
Pacific	155	179	200	220	230	252	231	240	249	242
U.S. total[2]	4,820	5,192	4,988	5,026	5,131	5,259	5,112	5,248	5,416	5,335

[1]Totals may not add due to rounding. Northeast = ME, NH, VT, MA, RI, CT, NY, NJ, PA, DE, and MD; Lake States = MI, WI, and MN; Corn Belt = OH, IN, IL, IA, and MO; Northern Plains = ND, SD, NE, and KS; Appalachia = VA, WV, NC, KY, and TN; Southeast = SC, GA, FL, and AL; Delta States = MS, AR, and LA; Southern Plains = OK and TX; Mountain = MT, ID, WY, CO, NM, AZ, UT, and NV; and Pacific = WA, OR, CA, AK, and HA.

[2]Excludes Puerto Rico. Detailed State data shown in (USDA, 1995).

Source: USDA, ERS, based on Tennessee Valley Authority, *Commercial Fertilizers*, 1994 and earlier issues; The Association of American Plant Food Control Officials, *Commercial Fertilizers, 1995-98*.

Table 4.4.3--Percent of acres receiving various nutrients, field crops in major producing States, 1997 or latest year available

		Commercial fertilizer						
Crop	Manure	Any	Nitrogen	Phosphate	Potash	Sulfur	Lime	Micro-nutrients
	Percent of acres							
Corn for grain (10 States)	17[7]	99	99	84	72	10[1]	5[1]	11[1]
Cotton (8 States)	5	91	90	65	52	20[1]	4[1]	20[1]
Fall potatoes (7 States)	2	100	99	9	89	64	6[2]	72
Rice (2 States)	3	98	98	34	37	10	2[3]	9
Soybeans:								
Northern (7 States)	9	36	16	24	32	2[1]	4[1]	3[1]
Southern (6 States)	2	40	19	35	38	1[4]	6[4]	2[4]
All wheat (12 States)	2[5]	88	87	63	18	10[6]	1[6]	2[6]

[1]1994. [2]1994 (11 States) [3]1991. [4]1993 (7 States). [5]1995 (15 States). [6]1994 (15 States). [7]1996.

Source: USDA, ERS. See table 4.4.4 for sources and historical data.

Table 4.4.4--Percent of acres receiving various nutrients, selected field crops in major producing States[1]

Crop, year	Manure	Commercial fertilizer	Commercial nitrogen	Commercial phosphate	Commercial potash	Sulfur	Lime	Micro nutrients
				Percent of acres				
Corn for grain (10 States):								
1985	NA	98	97	86	79	NA	NA	NA
1986	NA	96	95	84	76	NA	NA	NA
1987	16	96	96	83	75	3	2	5
1988	18	97	97	87	78	10	6	11
1989	15	97	97	84	75	8	5	11
1990	17	97	97	85	77	9	6	11
1991	19	97	97	82	73	10	4	11
1992	16	97	97	82	72	11	4	12
1993	16	97	97	82	71	10	4	11
1994	16	97	97	83	72	10	5	11
1995	14	98	97	81	72	NA	NA	NA
1996	17	98	98	86	75	NA	53[2]	NA
1997	NA	99	99	84	72	NA	55[2]	NA
Cotton (6 States):								
1985	NA	76	76	50	34	NA	NA	NA
1986	NA	80	80	50	39	NA	NA	NA
1987	3	76	76	47	33	7	1	9
1988	4	80	80	54	32	15	2	18
1989	2	79	79	54	32	21	2	15
1990	4	80	79	49	31	23	2	17
1991	3	81	81	52	34	20	2	18
1992	3	80	80	48	37	22	1	18
1993	4	85	85	54	36	23	3	18
1994	3	87	86	54	37	20	4	20
1995	3	87	87	56	40	NA	NA	NA
1996 (7 States)	NA	76	76	55	43	NA	24[2]	NA
1997 (8 States)	5	91	90	65	52	NA	26[2]	NA
Fall potatoes (11 States):								
1988	3	95	95	93	78	40	6	49
1989	4	99	98	94	83	48	7	52
1990	5	99	98	98	89	48	7	50
1991	4	99	99	98	88	52	4	56
1992	3	100	100	99	88	57	6	57
1993	4	100	100	98	91	58	6	58
1994	2	100	100	98	91	58	6	59
1995	2	100	99	98	89	NA	NA	NA
1996 (3 States)	NA	98	98	96	88	81	12[2]	78
1997 (7 States)	NA	98	98	96	89	64	15[2]	72
Rice (2 States):								
1988	1	99	99	46	36	7	NA	17
1989	*	99	99	46	33	5	NA	13
1990	*	98	97	36	37	13	1	14
1991	2	99	99	30	32	NA	2	11
1992	3	98	98	34	37	10	NA	9
Soybeans, Northern(7 States):								
1989	NA	30	14	23	28	2	6	3
1990	7	27	14	20	25	1	4	2
1991	6	26	14	19	22	1	4	2
1992	7	27	13	19	23	1	4	2
1993	7	26	12	18	24	1	4	2
1994	8	27	13	19	25	2	4	3
1995	5	27	16	19	23	NA	NA	NA
1996	NA	32	16	23	25	NA	54[2]	NA

1997	9	36	16	24	32	NA	59[2]	NA
Soybeans, Southern (7 States):								
1989	NA	44	24	42	44	2	6	3
1990	2	41	26	38	39	4	6	5
1991	3	37	21	33	35	1	6	3
1992	2	39	22	36	37	2	8	1
1993	2	38	22	34	36	1	6	2
1994 (Ak only)	2	37	17	32				
	34	1	4	2				
1995	2	36	21	31	33	NA	NA	NA
1996 (4 States)	NA	40	12	37	33	NA	23[2]	NA
1997 (6 States)	2	40	19	35	38	NA	40[2]	NA
All wheat (15 States):								
1985	NA	77	77	48	16	NA	NA	NA
1986	NA	79	79	48	19	NA	NA	NA
1987	3	80	80	50	15	7	1	1
1988	2	83	83	53	18	6	1	2
1989	3	81	81	53	18	7	1	2
1990	2	79	79	52	19	7	1	2
1991	4	80	80	54	20	7	1	1
1992	3	84	83	56	18	8	1	2
1993	3	87	86	60	17	9	1	2
1994	3	87	87	59	17	10	1	2
1995	2	87	87	63	18	NA	NA	NA
1996 (12 States)	NA	88	88	62	13	NA	6[2]	NA
1997	NA	88	87	63	18	NA	9[2]	NA

[1]Major producing states generally account for 80 percent or more of each crop's acreage. For States included see Table 4.4.21.
[2]Lime use question changed in 1996 from "Did you apply lime last year?" to "Have you ever applied lime on this field?"
NA = Not available. * = less than 0.5 percent.
Source: USDA, ERS Cropping Practices Survey and Agricultural Resource Management Study data.

Table 4.4.5--Average application rates of various nutrients on selected field crops in major producing States[1]

Crop, year	Commercial nitrogen	Commercial phosphate	Commercial potash	Sulfur	Lime
	Pounds/acre treated			*Tons/acre treated*	
Corn for grain (10 States):					
1985	140	60	84	NA	NA
1986	132	61	80	NA	NA
1987	132	61	85	NA	NA
1988	137	63	85	11	1.9
1989	131	59	81	9	1.4
1990	132	60	84	11	1.6
1991	128	60	81	11	1.7
1992	127	57	79	11	1.9
1993	123	56	79	15	1.7
1994	129	57	80	12	1.7
1995	129	56	81	NA	NA
1996	136	60	83	NA	2.3
1997	132	57	81	NA	2.3
Cotton (6 States):					
1985	80	46	52	NA	NA
1986	77	44	50	NA	NA
1987	82	44	45	NA	NA
1988	78	42	39	10	1.5
1989	84	43	40	23	1.3
1990	86	44	47	10	1.0
1991	91	47	48	12	1.0
1992	88	48	57	13	1.4
1993	89	47	58	13	1.0
1994	110	43	55	13	1.1
1995	95	43	51	NA	NA
1996 (7 States)	99	48	74	NA	1.2
1997 (8 States)	84	47	65	NA	1.2
Fall potatoes (11 States):					
1988	185	151	151	49	1.1
1989	192	157	155	61	1.0
1990	198	163	143	57	0.9
1991	195	158	143	59	0.9
1992	200	159	147	61	0.9
1993	206	167	156	68	1.0
1994	264	192	184	82	0.9
1995	221	171	170	NA	NA
1996 (3 States)	221	196	147	81	1.2
1997 (7 States)	237	182	156	76	1.1
Rice (2 States):					
1988	127	47	50	19	NA
1989	125	45	45	17	NA
1990	114	45	49	11	1.0
1991	127	46	47	15	NA
1992	134	44	50	18	NA
Soybeans, Northern (7 States):					
1989	16	48	77	10	1.5
1990	22	47	87	9	1.6
1991	24	49	80	12	2.0
1992	20	46	76	10	2.0

1993	18	47	83	15	1.5
1994	24	46	83	13	1.8
1995	27	55	91	NA	NA
1996	24	49	90	NA	2.3
1997	20	53	95	NA	2.3
Soybeans, Southern (7 States):					
1989	21	43	67	10	1.5
1990	28	47	70	20	1.1
1991	28	45	70	12	1.2
1992	27	49	74	9	1.0
1993	24	44	70	22	0.9
1994 (Ak only)	34	48	66	NA	1.3
1995	37	51	68	NA	NA
1996 (4 States)	28	48	66	NA	1.7
1997 (6 States)	44	54	85	NA	1.4
All wheat (15 States):					
1985	60	35	36	NA	NA
1986	60	36	44	NA	NA
1987	62	35	43	NA	NA
1988	64	37	52	12	2.2
1989	62	37	46	12	1.9
1990	59	36	44	9	1.8
1991	62	36	43	11	1.4
1992	63	34	39	13	1.4
1993	64	34	35	14	1.7
1994	67	35	38	11	1.7
1995	65	33	38	NA	NA
1996 (12 States)	63	30	25	NA	2.5
1997	67	32	40	NA	2.0

[1]Data not available for manure or micronutrients. Major producing States generally account for 80 percent or more of each crop's acreage. For the States included, see table 4.4.21.

NA = Not available.

Source: USDA, ERS Cropping Practices Survey and Agricultural Resource Management Study data.

Table 4.4.6--Average U.S. farm prices of selected fertilizers, 1960-99

Year[1]	Anhydrous ammonia	Nitrogen solutions (30%)	Urea (45-46% nitrogen)	Ammonium nitrate	Sulfate of ammonium	Super-phosphate (20% phosphate)	Super-phosphate (44-46% phosphate)	Diammonium phosphate (18-46-0)	Potassium chloride (60% potassium)
	Nominal dollars per ton								
1960	141	NA	117	82	58	38	79	NA	51
1961	142	NA	114	83	58	38	81	NA	52
1962	134	NA	109	82	57	38	80	NA	53
1963	128	NA	107	81	52	41	81	NA	54
1964	126	NA	106	80	53	40	81	NA	54
1965	122	NA	104	79	53	41	81	NA	54
1966	119	NA	101	77	53	41	81	NA	55
1967	113	67	99	74	54	42	84	113	54
1968	91	63	92	68	54	43	78	101	49
1969	76	54	84	62	53	44	74	94	48
1970	75	54	83	60	52	45	75	94	51
1971	79	56	82	63	52	48	77	96	58
1972	80	55	81	65	52	50	78	97	59
1973	88	58	90	71	55	54	88	109	62
1974	183	111	183	139	110	91	150	181	81
1975	265	153	244	186	148	118	214	263	102
1976	191	113	166	135	98	95	158	189	96
1977	188	122	169	141	101	99	146	180	96
1978	177	118	169	140	109	104	151	186	96
1979	171	110	170	138	118	109	161	199	107
1980	229	134	221	165	138	128	247	297	135
1981	243	141	237	185	150	134	248	287	152
1982	255	151	240	195	165	NA	230	267	155
1983	237	142	214	185	149	NA	214	249	143
1984	275	145	222	198	150	NA	229	271	145
1985	255	143	221	192	156	NA	206	244	128
1986	225	122	174	171	149	NA	190	224	111
1987	187	109	161	157	144	NA	194	220	115
1988	208	137	183	166	140	NA	222	251	157
1989	224	142	212	189	154	NA	229	256	163
1990	199	132	184	180	154	NA	201	219	155
1991	210	138	212	184	151	NA	217	235	156
1992	208	141	198	178	151	NA	206	224	150
1993	213	137	202	186	157	NA	190	199	146
1994	243	137	207	196	170	NA	212	224	146
1995	330	169	266	223	182	NA	234	263	155
1996	303	182	278	233	184	NA	258	294	153
1997	303	160	257	227	185	NA	257	272	152
1998	253	134	195	193	187	NA	253	264	163
1999	211	128	176	181	171	NA	255	264	168

NA = Not available.

[1]April prices for 1960-76, 1986-99; all other prices are for March.

Source: USDA-NASS, *Agricultural Prices*, 1961-99.

Table 4.4.7--Nitrogen mass balances for selected crops in major producing States, 1990-97[1]

Crop and year	Acres	Nutrient inputs: Commercial fertilizer	Previous legumes	Manure	Total	Nutrient output in harvested cropland	Average	Nutrient mass balance: Above 25 percent	0-25 percent	Negative
	1,000	*Average pounds per acre*						*Percent of acres*		
Corn										
1990	58,700	130	21	6	157	113	44	63	17	20
1991	60,350	128	22	7	157	102	55	67	14	19
1992	62,700	128	22	6	156	128	28	48	25	27
1993	57,300	123	24	6	153	92	61	75	9	16
1994	62,500	127	21	6	154	131	23	42	26	32
1995	52,200	130	28	2	160	105	55	69	12	19
1996	56,788	134	25	5	162	125	38	58	20	22
Cotton										
1990	8,444	68	3	3	74	54	20	47	8	46
1991	10,850	79	3	4	86	62	24	47	12	41
1992	10,115	86	1	4	91	60	31	61	10	29
1993	10,126	80	2	3	85	57	28	57	8	35
1994	10,023	95	2	4	101	61	40	57	9	34
1995	10,480	82	2	3	87	47	40	63	8	29
1997	9169	73	4	1	78	60	18	48	16	36
Potatoes										
1990	624	191	7	5	203	149	54	56	9	35
1991	655	176	4	1	181	141	40	59	8	33
1992	607	183	3	1	187	161	26	56	6	38
1993	647	177	3	1	181	139	42	60	8	32
1994	652	246	3	--	249	142	107	64	10	26
1995	669	206	1	1	208	138	70	59	15	26
Wheat, winter										
1990	38,650	51	0	1	52	49	3	36	12	52
1991	30,980	53	5	1	59	41	18	52	9	39
1992	33,465	54	4	1	59	44	15	50	11	39
1993	35,210	53	4	1	58	48	10	46	7	47
1994	32,930	56	4	1	61	45	16	48	14	38
1995	32,670	57	6	1	64	43	21	54	9	1

-- = Less than 0.5.

[1]See Cropping Practices Survey in the appendix for major producing States included.

Source: USDA, ERS, estimates based on Cropping Practices Survey and Agricultural Resource Management Study data (see box, Computing Nutrient Mass Balances).

Table 4.4.8--Phosphate mass balances for selected crops in major producing States, 1990-97[1]

Crop and year	Acres	Nutrient inputs: Commercial fertilizer	Previous legumes	Manure	Total	Nutrient output in harvested cropland	Average	Nutrient mass balance: Above 25 percent	0-25 percent	Negative
	1,000	*Average pounds per acre*						*Percent of acres*		
Corn										
1990	58,700	52	0	6	58	44	14	50	12	38
1991	60,350	52	0	7	59	40	19	54	11	36
1992	62,700	47	0	5	52	50	2	36	14	50
1993	57,300	47	0	6	53	36	17	57	10	33
1994	62,500	48	0	6	54	51	3	37	13	50
1995	52,200	47	0	2	49	41	8	43	11	46
1996	56,788	52	0	5	55	49	7	43	13	45
Cotton										
1990	8,444	23	0	2	25	26	-1	36	5	59
1991	10,850	26	0	3	29	30	-1	39	5	57
1992	10,115	27	0	4	31	29	2	33	7	60
1993	10,126	26	0	3	29	28	1	40	5	55
1994	10,023	24	0	4	28	30	-2	36	7	57
1995	10,480	23	0	2	25	23	2	40	6	55
1997	9169	25	0	1	27	30	-3	32	10	58
Potatoes										
1990	624	159	0	6	165	28	137	92	2	6
1991	655	43	0	1	144	27	117	89	3	8
1992	607	146	0	1	147	30	117	88	3	9
1993	647	148	0	1	149	26	123	94	2	4
1994	652	171	0	-	171	27	144	92	2	6
1995	669	157	0	1	158	26	132	91	3	6
Soybeans										
1990	39,600	10	0	3	13	34	-21	13	4	83
1991	41,850	9	0	3	12	33	-21	13	3	84
1992	41,600	10	0	3	13	37	-24	11	7	82
1993	42,300	9	0	3	12	32	-20	13	5	82
1994	43,750	10	0	3	13	40	-27	9	5	86
1995	41,700	11	0	1	12	35	-22	13	3	84
1997	46,650	13	0	3	15	40	-25	13	4	84
Wheat, winter										
1990	38,650	19	0	1	20	25	-5	28	7	65
1991	30,980	20	0	1	21	21	0	33	8	59
1992	33,465	18	0	1	19	22	-3	31	6	63
1993	35,210	19	0	1	20	24	-4	31	5	64
1994	32,930	19	0	1	20	23	-3	30	8	62
1995	32,670	20	0	1	21	22	-1	36	5	59

-- = Less than 0.5.

[1]See Cropping Practices Survey in the appendix for major producing States included.

Source: USDA, ERS, estimates based on Cropping Practices Survey and Agricultural Resource Management Study data (see box, Computing Nutrient Mass Balances).

Table 4.4.9--Nutrient management operations and improved versus conventional practices

Nutrient management operation	Conventional practices	Improved practices
Assessing nutrient need	Limited testing for residual nutrient levels, or plant tissue tests to detect nutrient deficiency in plant before applying nutrients.	Annual or regular soil and plant tissue testing before applying nutrients.
	Limited use of the nutrient mass balance accounting method to determine appropriate application rate. Amount applied based on recommendation rates for yield maximization, with no crediting for nutrients from other sources.	Nutrient mass balance accounting method to determine appropriate application rate based on recommendation rate for realistic yield goal, with crediting given for nutrients in previous legume, irrigation water, and manure. Manure analyzed for nutrients.
	Same application rate on all parts of field.	Nutrient application rates varied according to the yield potential of soil in various parts of the field.
	The importance of soil factors overlooked.	Optimal levels of soil factors-- such as soil pH, organic matter, and micro-nutrients-- maintained.
Timing nutrient application	Fall and early spring applications of nitrogen before planting.	Split application of nitrogen fertilizer at planting and after planting.
	Application sometimes made before expected heavy rain.	No application before expected heavy rain.
Nutrient placement	Ground and air broadcast, and application in furrow.	Banded and injected (knifed-in) applications and chemigation.
Nutrient product selection	Nitrate-based fertilizer sometimes used on high-leaching field, and ammonia-based fertilizer on high-volatilization field.	Ammonia-based fertilizer used on high leaching field, and nitrate-based fertilizer for low-leaching field. Nitrogen stabilizers used in ammonia-based nitrogen fertilizer.
	No application of manure to increase organic matter in soil.	Manure applied to increase organic matter in soil.
Crop selection and management	Continuous planting of same nitrogen-using crop. No planting of cover crops between crop seasons.	Nitrogen-using crops rotated with nitrogen-fixing crops. Cover crops planted between crop seasons to tie up and preserve nutrients.
Irrigation management	Conventional gravity irrigation with an excessive application of water.	Improved gravity irrigation practices or sprinkler irrigation used to apply water more timely and uniformly according to crop needs.
Manure and organic waste management	Crop residues removed. No manure or organic waste applied. No manure testing. Inadequate manure storage for properly timing manure applications.	Manure and organic waste application based on manure and waste test results and nutrient management plan. Adequate manure storage for timing manure application, with manure injected or incorporated into soil.

Source: USDA,ERS;
http://www.ftw.nrcs.usda.gov/te ch_ref.html

Table 4.4.10--Nutrient management practices on corn, major producing States, 1990-97[1]

Activities and practices	1990	1991	1992	1993	1994	1995	1996	1997
Nutrient sources:	*Percent of planted acres*							
Commercial fertilizer	97	97	97	97	98	98	98	99
Manure	17	19	16	18	16	14	17	na
Commercial and manure	16	18	15	17	15	13	16	na
Previous soybeans	40	40	44	46	48	50	57	64
Assessing nutrient needs:	*Percent of planted acres[2]*							
Soil tested	41	41	42	38	42	34	45	43
Tested for N	61	60	82	77	54	53	47	40
Applied recommended N	na	na	85	87	84	78	69	72
Applied > recommended	na	na	5	3	7	7	13	17
Applied < recommended	na	na	10	10	9	14	18	11
Manure analyzed for manure-treated acres	na	na	na	na	6	8	na	na
N adjusted for manure-analyzed acres	na	na	na	na	70	na	na	na
N adjusted for previous legume	na	na	na	na	53	54	na	na
Timing nutrient application:	*Percent of acres receiving commercial fertilizer*							
Nitrogen timing:								
Fall before planting	27	26	23	20	27	30	22	27
Spring before planting	57	50	53	51	54	52	54	51
At planting	44	48	47	48	43	42	43	44
After planting	26	31	31	35	27	29	33	30
Phosphate timing:								
Fall before planting	na	na	na	na	25	26	26	29
Spring before planting	na	na	na	na	34	31	31	31
At planting	na	na	na	na	48	48	46	47
After planting	na	na	na	na	2	2	7	2
Nutrient placement:	*Percent of acres receiving commercial fertilizer*							
Broadcast (ground)	71	72	69	71	72	73	73	71
Broadcast (air)	na	na	1	1	1	1	1	1
Chemigation	1	2	1	1	1	1	2	2
Banded	43	41	42	42	41	40	40	43
Foilar	1	0	0	-	-	0	1	2
Injected (knifed in)	55	53	54	47	53	51	54	48
Nutrient product selection:	*Percent of planted acres*							
N fertilizer mixed with N inhibitors	8	9	8	5	9	10	11	na

na = no data collected. - means less than 0.5.

[1]For States included, see appendix 2. [2]Indented items are a percentage of previous non-indented item.

Source: USDA, ERS, Cropping Practices Survey and Agricultural Resource Management Study data.

Table 4.4.11--Nutrient management practices on soybeans, major producing States, 1990-97[1]

Activities and practices	1990	1991	1992	1993	1994	1995	1996	1997
Nutrient sources:				*Percent of planted acres*				
Commercial fertilizer	27	26	27	27	28	28	33	37
Manure	6	5	6	6	8	5	na	8
Commercial and manure	2	2	2	1	2	1	na	2
Soybeans	12	10	20	11	12	11	19	19
Assessing nutrient need:				*Percent of planted acres[2]*				
Soil tested	26	28	28	28	30	25	27	34
Tested for N	15	16	29	29	43	41	30	na
Applied recommended N	na	na	85	87	76	74	65	na
Applied > recommended	na	na	5	3	5	7	11	na
Applied < recommended	na	na	10	10	18	19	24	na
Manure analyzed for manure-treated acres	na	na	na	na	5	8	24	na
N adjusted for manure-analyzed acres	na	na	na	na	75	na	na	na
N Adjusted for previous legume	na	na	na	na	16	na	na	na
Timing nutrient application:				*Percent of acres receiving commercial fertilizer*				
Nitrogen timing:								
Fall before planting	25	26	33	27	31	35	22	36
Spring before planting	50	46	43	51	42	43	47	43
At planting	22	24	17	21	24	19	18	17
After planting	7	8	8	4	7	8	15	9
Phosphate timing:								
Fall before planting	na	na	na	na	42	41	37	44
Spring before planting	na	na	na	na	40	42	41	43
At planting	na	na	na	na	17	16	13	12
After planting	na	na	na	na	3	2	10	2
Nutrient placement:				Percent of acres receiving commercial fertilizer				
Broadcast (ground)	87	85	89	90	88	88	91	93
Broadcast (air)	na	na	na	1	2	2	1	1
Chemigation	1	2	1	1	-	-	1	-
Banded	14	14	9	9	11	11	6	6
Injected (knifed in)	2	4	1	1	2	3	3	1

na = no data collected. - means less than 0.5.

[1]For States included, see appendix 2. [2]indented items are a percentage of previous non-indented item.

Source: USDA, ERS, Cropping Practices Survey and Agricultural Resource Management Study data.

Table 4.4.12--Nutrient management practices on cotton, major producing States, 1990-97[1]

Activities and practices	1990	1991	1992	1993	1994	1995	1996	1997
Nutrient sources:				*Percent of planted acres*				
Commercial fertilizer	80	82	80	85	87	87	76	91
Manure	4	3	3	4	3	3	na	5
Commercial and manure	20	2	3	3	3	3	na	4
Assessing nutrient need:				*Percent of planted acres[2]*				
Soil tested	28	32	27	28	33	27	41	44
Tested for N	95	88	98	94	88	95	74	65
Applied recommended N	na	na	76	79	81	73	60	62
Applied > recommended	na	na	13	19	9	14	26	20
Applied < recommended	na	na	11	8	10	13	14	18
Tissue tested	na	na	na	na	12	na	na	9
Tested for N	na	na	na	na	96	na	na	na
Applied recommended N	na	na	na	na	97	na	na	na
Applied > recommended	na	na	na	na	0	na	na	na
Applied < recommended	na	na	na	na	3	na	na	na
Manure analyzed for manure-treated acres	na	na	na	na	23	31	na	na
N adjusted for manure-analyzed acres	na	na	na	na	100	na	na	na
N adjusted for previous legume	na	na	na	na	36	na	na	na
Timing nutrient application:				*Percent of acres receiving commercial fertilizer*				
Nitrogen timing:								
Fall before planting	30	32	30	30	31	32	11	31
Spring before planting	42	46	36	43	45	43	64	43
At planting	8	11	10	8	7	7	7	11
After planting	56	57	59	58	53	52	63	59
Phosphate timing:								
Fall before planting	na	na	na	na	40	37	15	37
Spring before planting	na	na	na	na	49	47	68	49
At planting	na	na	na	na	4	4	9	9
After planting	na	na	na	na	11	17	13	11
Nutrient placement:				*Percent of acres receiving commercial fertilizer*				
Broadcast (ground)	56	58	55	55	60	55	72	68
Broadcast (air)	na	5	6	6	3	3	3	3
Chemigation	7	8	6	6	8	6	8	5
Banded	24	27	25	24	20	29	14	27
Foilar	0	4	3	2	-	-	5	3
Injected (knifed in)	45	45	42	45	46	40	45	40
Nutrient product selection:				*Percent of planted acres*				
N fertilizer mixed with N inhibitors	4	6	3	3	4	na	na	3

na = no data collected. - means less than 0.5.
[1]For States included, see ACropping Practices Survey@ in appendix 2. [2]indented items are a percentage of previous non-indented item.
Source: USDA, ERS, Cropping Practices Survey and Agricultural Resource Management Study data.

Table 4.4.13--Nutrient management practices on fall potatoes, major producing States 1990-97[1]

Activities and practices	1990	1991	1992	1993	1994	1995	1996	1997
Nutrient sources:				*Percent of planted acres*				
Commercial fertilizer	99	99	100	100	100	100	98	98
Manure	5	4	3	4	2	2	na	na
Commercial and manure	5	4	3	3	2	2	na	na
Assessing nutrient need:				*Percent of planted acres[2]*				
Soil tested	83	84	82	84	85	83	92	88
Tested for N	77	77	82	84	92	94	92	93
Applied recommended N	na	na	79	77	76	73	63	59
Applied > recommended	na	na	9	11	10	10	11	16
Applied < recommended	na	na	12	12	14	17	26	25
Tissue tested	na	na	na	na	61	na	na	67
Tested for N	na	na	na	na	60	na	na	na
Applied recommended N	na	na	na	na	83	na	na	na
Applied > recommended	na	na	na	na	3	na	na	na
Applied < recommended	na	na	na	na	14	na	na	na
Manure analyzed for manure-treated acres	na	na	na	na	13	43	na	na
N adjusted for manure-analyzed acres	na	na	na	na	13	na	na	na
N adjusted for previous legume	na	na	na	na	54	na	na	na
Timing nutrient application:				*Percent of acres receiving commercial fertilizer*				
Nitrogen timing:								
Fall before planting	16	22	19	20	30	28	19	26
Spring before planting	37	41	36	35	43	40	64	50
At planting	59	56	53	54	41	46	46	40
After planting	52	60	57	57	63	73	72	66
Phosphate timing:								
Fall before planting	na	na	na	na	28	27	18	26
Spring before planting	na	na	na	na	39	37	60	46
At planting	na	na	na	na	41	46	45	41
After planting	na	na	na	na	28	30	41	27
Nutrient placement:				*Percent of acres receiving commercial fertilizer*				
Broadcast (ground)	na	na	na	na	76	79	83	76
Broadcast (air)	na	na	na	na	9	7	2	5
Chemigation	na	na	na	na	45	48	48	47
Banded	na	na	na	na	51	47	46	49
Foilar	na	na	na	na	2	-	1	4
Injected (knifed in)	na	na	na	na	6	14	21	6
Nutrient product selection:				*Percent of planted acres*				
N fertilizer mixed with N inhibitors	4	4	2	6	5	na	na	na

na = no data collected. - means less than 0.5.

[1]For States included, see ACropping Practices Survey@ in appendix 2. [2]Indented items are a percentage of previous non-indented item.

Source: USDA, ERS, Cropping Practices Survey and Agricultural Resource Management Study data.

Table 4.4.14--Nutrient management practices on winter wheat, major producing States 1990-97[1]

Activities and practices	1990	1991	1992	1993	1994	1995	1996[3]	1997
Nutrient sources:	*Percent of planted acres*							
Commercial fertilizer	83	83	84	86	86	86	87	86
Manure	2	3	3	3	3	3	na	na
Commercial and manure	1.8	3	2	3	2	1	na	na
Previous legume hay and pasture	4	1	1	-	1	1	na	na
Assessing nutrient need:	*Percent of planted acres[2]*							
Soil tested	17	19	23	22	20	22	26	26
Tested for N	92	92	95	93	91	91	98	86
Applied recommended N	na	na	77	77	78	63	48	52
Applied > recommended	na	na	7	9	7	15	9	24
Applied < recommended	na	na	16	15	15	21	43	24
Manure analyzed for manure-treated acres	na	na	na	na	na	12	na	na
N adjusted for manure-analyzed acres	na	na	na	na	na	13	na	na
Timing nutrient application:	*Percent of acres receiving commercial fertilizer*							
Nitrogen timing								
Fall before planting	68	73	73	72	76	77	69	74
At planting	22	22	21	22	23	23	31	22
After planting	44	45	47	44	42	47	29	44
Phosphate timing:								
Fall before planting	na	na	na	na	57	57	39	57
At planting	na	na	na	na	38	38	54	39
After planting	na	na	na	na	7	7	8	5
Nutrient placement:	*Percent of acres receiving commercial fertilizer*							
Broadcast (ground)	na	na	na	na	58	62	45	57
Broadcast (air)	na	na	na	na	3	3	1	2
Chemigation	na	na	na	na	1	1	1	2
Banded	na	na	na	na	19	21	49	24
Injected (knifed in)	na	na	na	na	46	46	50	36
Nutrient product selection:	*Percent of planted acres*							
N fertilizer mixed with N inhibitors	3	2	2	1	2	na	na	na

na = no data collected. - means less than 0.5.

[1]For States included, see ACropping Practices Survey@ in appendix 2. [2]Indented items are a percentage of previous non-indented item.

Source: USDA, ERS, Cropping Practices Survey and Agricultural Resource Management Study data.