Nitrogen loss

Modeling the nitrogen cycle

Nitrogen is a necessary input for crop growth and production. Along with carbon and phosphorus, nitrogen provides the organic building blocks for plant growth and crop yield. Although the atmosphere is 78 percent nitrogen gas, it cannot be directly used by plants. Nitrogen molecules in the air are inert, mainly existing as two nitrogen atoms strongly bonded together (di-nitrogen gas). To be used by plants, the di-nitrogen molecules must be split apart and converted into ammonium or nitrate compounds that plants can take up and metabolize—a process called nitrogen fixation. Most nitrogen fixation is the product of biochemical processes performed by soil microorganisms. A small amount of nitrogen is converted by lightning and ultraviolet rays. Plant available nitrogen is usually in short supply under natural conditions, limiting plant growth and biomass production.

Most soil nitrogen is bound up in soil organic matter, which is partially decomposed plant and animal residue. As soil microbes consume the organic matter, ammonium or nitrate nitrogen is released, allowing the nitrogen to be recycled as plant uptake. Decomposition of organic matter, or mineralization, is typically a slow process that may take from several months to hundreds or even thousands of years, depending on the type of organic material. Intensive tillage of cropland and the introduction of oxygen into the soil increases mineralization and speeds the release of plant available nitrogen from organic sources in the soil.

Modern farming practices include the application of commercial fertilizers and manure to promote plant growth and increase crop yields. Commercial fertilizers, which are produced through chemical industrial processes, and manure applications are the primary sources of nitrogen applied. Planting soybeans, peas, and other legume crops that host symbiotic nitrogen-fixing bacteria are also an important source of plant-available nitrogen. Another source of nitrogen is atmospheric deposition. Ammonia and nitrogen oxide gasses are released into the atmosphere as a by-product from modern industrial societies (for instance, automobile emissions), from livestock and livestock production facilities, and from volatilization and denitrification of applied fertilizers, decomposing organic matter, and other soil nitrogen. These nitrogen compounds may drift with the wind and be re-deposited on cropland with rainfall or as dry deposition.

Some forms of nitrogen fertilizer, such as anhydrous ammonia, and most livestock manures contain a high percentage of ammonium nitrogen, which is highly volatile. To prevent significant loss of this nitrogen at the time of application, ammonium forms of commercial fertilizer and manures are incorporated or injected into the soil. Rainfall or application of irrigation water soon after application of manure or ammonia fertilizers will also reduce loss of ammonia. Nitrate nitrogen fertilizers are generally not volatile, but can lead to nitrogen loss to the atmosphere through denitrification processes if applied to fields where the soil moisture content is near saturation. Chemical products can be added to nitrogen fertilizers and manures to reduce the release of gaseous nitrogen.

The nitrogen cycle as simulated by EPIC consists of mineral and organic fractions (fig. 13). Organic nitrogen is partitioned into fresh, stable, and active pools, while mineral nitrogen is partitioned into ammonium or nitrate pools. The model tracks nitrogen transformations between pools within each fraction and also between the organic and mineral fractions on a daily time-step through a series of coupled equations that are solved within a mass balance framework. These equations are closely tied to other model components including the hydrology component, which controls most of the transport processes, and the plant growth component, which handles plant uptake. EPIC mineralization and immobilization transformations are based upon the PAPRAN (Seligman and Van Keulen 1981) model. Plant uptake of nitrogen is estimated using a supply and demand approach, which balances available nitrogen with an ideal nitrogen concentration in the plant for a given day.

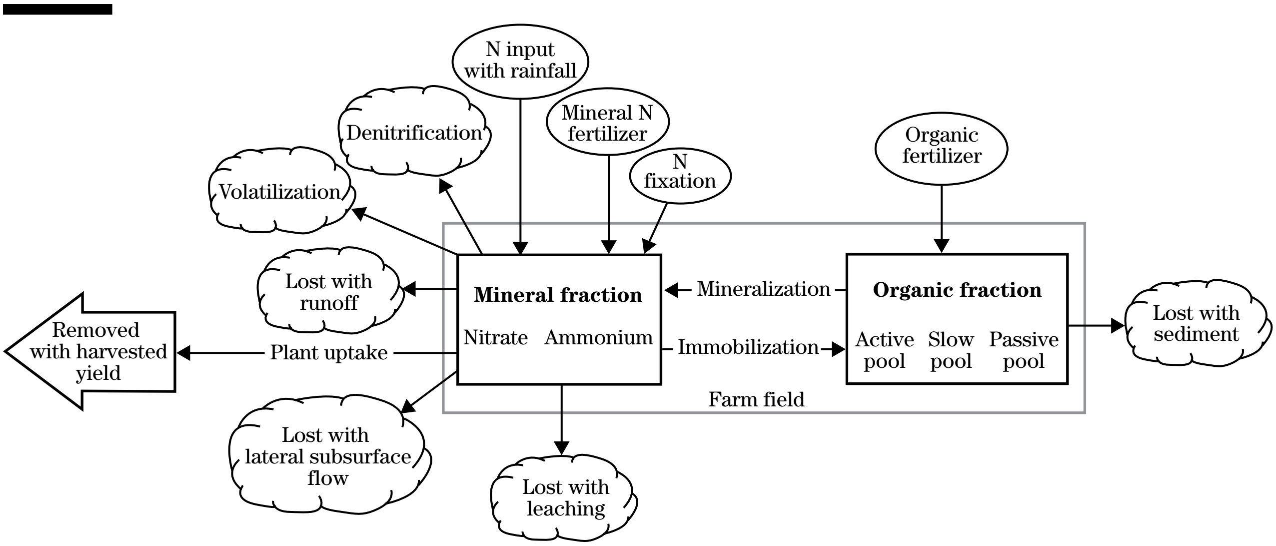
Nitrogen inputs in EPIC simulations include nitrogen applied as ammonia, nitrate, and organic (manure) fertilizers, symbiotic bio-fixation associated with legume crops, and soluble nitrogen deposited with rainfall. Commercial nitrogen fertilizer data used in EPIC model simulations were derived from farmer surveys, as described in a previous section of this report. Manure nitrogen applications used in EPIC model simulations were derived from data on livestock populations, also described in a previous section of this report. Daily nitrogen fixation from legumes is estimated as a fraction of daily plant uptake. Daily plant uptake is modeled as a function of soil nitrate concentration, soil-water content, and plant growth stage. The growth stage factor inhibits nitrogen fixation in young plants prior to development of functional nodules and in old plants with senescent nodules. For rainfall depositions, the rainfall concentration of soluble nitrogen was set at 0.8 parts per million. Thus, for each inch of rainfall, 0.181 pounds per acre of nitrogen was added to the system in the form of nitrate. Dry deposition and lightning fixation inputs were not included in the simulations.

EPIC simulates nitrogen exports from the field in two forms: crop removal and losses to the air and water. Nitrogen contained in the plant material is partitioned between that which is removed from the field with the harvested crop yield and that portion remaining in the residue which is added into the organic pools. Nitrogen losses include nitrates dissolved in surface runoff, percolation (leachate), and lateral subsurface flow; organic nitrogen attached to wind and waterborne sediment; and ammonia and nitrogen oxides lost to the atmosphere.

Nitrate losses in surface water runoff, lateral subsurface flow and percolation are estimated as products of the volume of water and the average concentration of nitrate in the soil layer. Organic nitrogen transport with sediment is calculated with a loading function developed by McElroy et al. (1976) and modified by Williams and Hann (1978) for application to individual runoff events. The loading function estimates the daily organic nitrogen runoff loss based on the concentration of organic nitrogen in the top soil layer, sediment yield, and nutrient enrichment ratio. The enrichment ratio is the concentration of organic nitrogen in sediment divided by that in soil. Volatilization is estimated simultaneously with the conversion of ammonia-nitrogen to nitrate-nitrogen in the nitrification process. Partitioning is regulated by a function of temperature, soil-water content, and soil pH for nitrification, while below surface volatilization is controlled by depth of ammonia within the soil, cation exchange capacity of the soil, and soil temperature. Volatilization of surface-applied ammonia is estimated as a function of temperature and wind speed.

Denitrification is an anaerobic microbial process, occurring under saturated soil moisture conditions,

Figure 13 Nitrogen cycle as modeled in EPIC



that reduces nitrates to nitrogen oxides and di-nitrogen gas molecules that are lost to the atmosphere. Denitrification rates can range from 5 to 20 percent of applied nitrogen. In EPIC, denitrification rates are regulated by a function of temperature and soil-water content that is parameterized as the fraction of field capacity soil water storage. This threshold was set at 1.01 for all model simulations conducted in this study, which resulted in no denitrification. As discussed in a previous section, the minimum depth of the water table was also set to 2 meters year-round for all model runs to simulate adequate drainage. While the assumption of adequate drainage during the crop production time period is generally desirable, the model simulations reported in this study did not account for high water tables and denitrification during times of the year when drainage is not critical for crop production (after harvest and during winter months), which is when saturated soil conditions and denitrification most often occur on cropland acres. By not accounting for poor drainage and denitrification outside of the growing season, model estimates of nitrates in leachate may be overstated in some cases, nitrates in surface water runoff may be understated in some cases, and nitrogen volatilization estimates may be understated in some cases. Total nitrogen loss, however, is generally not affected by these modeling assumptions. (In this study, nitrogen volatilization includes both gaseous nitrogen lost as ammonia, usually at the time of nitrogen application, and di-nitrogen and nitrous oxide gases generated through denitrification processes, which take place over longer periods of time.)

For comparisons of nitrogen loss to nitrogen inputs in this report, nitrogen inputs included commercial fertilizer, manure applications, bio-fixation, and atmospheric deposition. Nitrogen input from mineralization of soil organic matter is not reported or included in these comparisons, but did contribute to the pool of mineral nitrogen in the EPIC model and, therefore, is reflected in nitrogen loss estimates. In addition, it is recognized that the organic portion of manure nitrogen is not immediately available to the plant, and that the portion of manure nitrogen that is not available for plant growth in the year of application is available in subsequent years. As simulated by EPIC, manure nitrogen inputs in a given year are equal to the mineral form of nitrogen (mostly as ammonia) in the manure applied during the current year and mineralized nitrogen from the organic fraction of manure applications in previous years.

EPIC also calculates a complete daily mass balance of nitrogen, including mineralization and immobilization between the organic and mineral fractions, transformations between the pools within each fraction, and residue additions. These model outputs were not tracked or reported in this study.

Model simulation results for nitrogen inputs

Nitrogen inputs from commercial fertilizer applications, manure applications, bio-fixation, and atmospheric deposition totaled about 21 million tons per year for the 298 million acres of cropland represented by the model simulations (table 33). Of this, 49 percent (10.4 million tons) came from symbiotic bacterial-legume fixation (bio-fixation), 41 percent (8.7 million tons) was added as commercial fertilizer, 5 percent (1.1 million tons) was added as manure, and 4 percent (0.8 million tons) was added with rainfall. Soybeans, corn, and legume hay had the largest inputs with 6.3, 5.2, and 5.0 million tons per year, respectively (table 33). About half of total commercial nitrogen fertilizer and about half of the total manure nitrogen was applied to corn. The preponderance of the nitrogen inputs for the three legume crops—soybeans, peanuts, and alfalfa hay—came from bio-fixation, with relatively small amounts coming from other sources. Atmospheric deposition of nitrogen was treated in the model as a fixed concentration, but varied in importance from region to region because of differences in the amount of rainfall and cropland acres. Nitrogen from these four sources, together with soil organic nitrogen converted each year from organic to mineral form, was available for plant growth in the EPIC model simulations, where they were either taken up by the crop and removed from the field at harvest, stored in the soil, or transported from the field by wind and water.

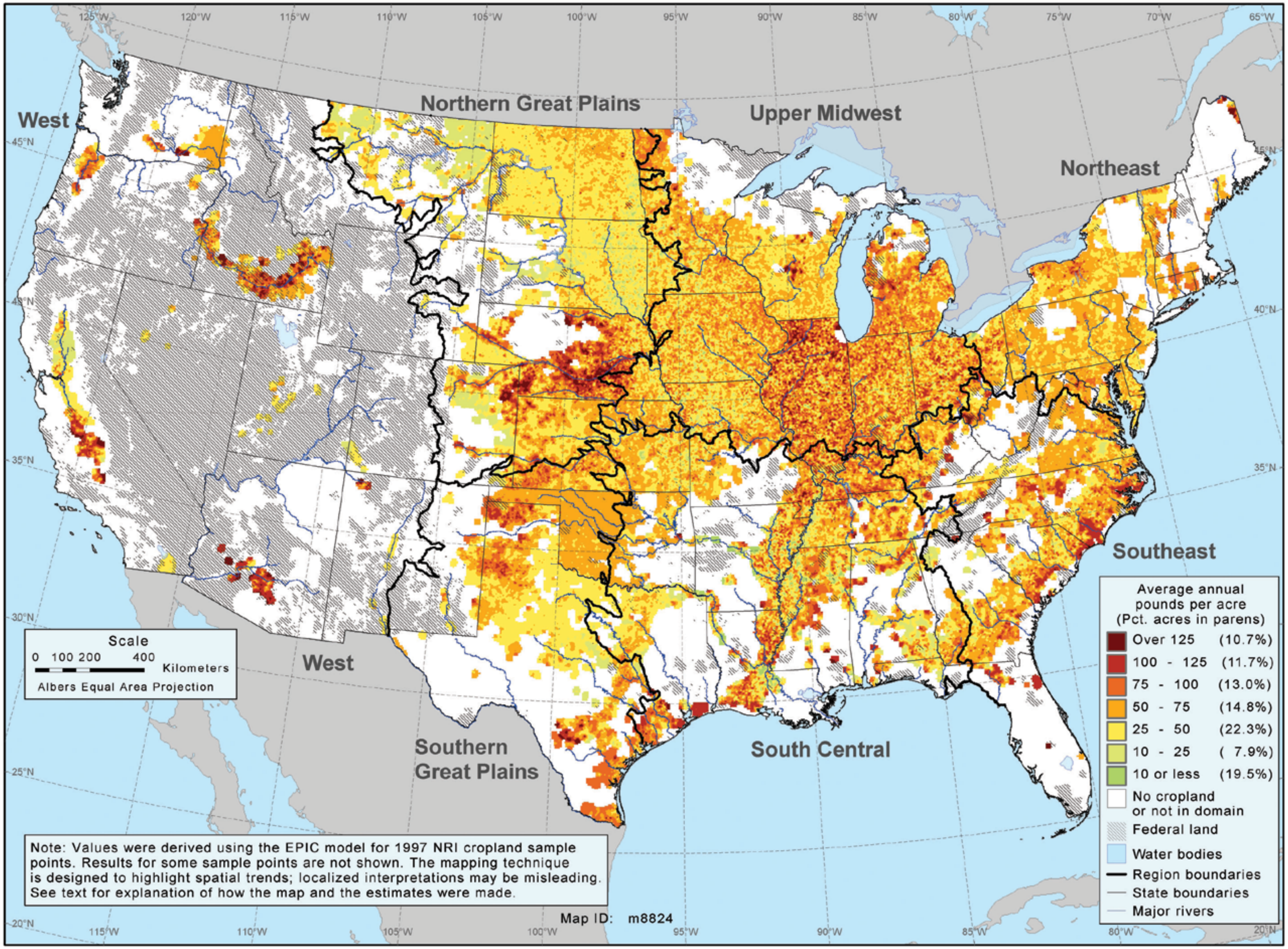
Spatial trends in nitrogen application rates

Map 13 shows the spatial distribution of average commercial fertilizer application rates that are based on the inputs used for the EPIC model simulations. Commercial fertilizer application rates varied substantially throughout most of the cropland acres, reflecting the crop mix and the associated differences in application rates by crop. The color pattern in corn and soybean production areas, for example, mainly represents the mix of corn acres receiving substantial commercial

Table 33 Sources of nitrogen inputs–by region and by crop (average annual values)

	Acres		Commercial fertilizer		Manure		Atmospheric deposition		Bio-fixation		Sum of inputs	
	1,000s	Percent	Tons	Percent	Tons	Percent	Tons	Percent	Tons	Percent	Tons	Percent
By region												
Northeast	13,642	4.6	388,665	4.5	146,867	13.6	48,523	5.8	1,081,687	10.4	1,665,742	7.9
Northern Great Plains	72,397	24.3	1,815,130	20.9	154,986	14.3	122,474	14.6	907,910	8.7	3,000,645	14.3
South Central	45,350	15.2	1,290,546	14.8	85,795	7.9	197,007	23.4	1,993,185	19.2	3,566,628	17.0
Southeast	13,394	4.5	423,992	4.9	82,103	7.6	55,854	6.6	468,580	4.5	1,030,529	4.9
Southern Great Plains	32,096	10.8	952,920	11.0	74,517	6.9	61,552	7.3	106,041	1.0	1,195,054	5.7
Upper Midwest	112,581	37.7	3,504,461	40.3	466,355	43.1	344,878	41.0	5,579,239	53.6	9,894,962	47.1
West	9,018	3.0	318,839	3.7	71,619	6.6	10,313	1.2	263,443	2.5	664,220	3.2
All regions	298,478	100.0	8,694,553	100.0	1,082,242	100.0	840,601	100.0	10,400,085	100.0	21,017,780	100.0
By crop												
Barley	4,635	1.6	171,683	2.0	2,244	0.2	7,313	0.9	0	0.0	181,242	0.9
Corn	78,219	26.2	4,369,865	50.3	552,495	51.1	231,507	27.5	0	0.0	5,153,867	24.5
Corn silage	5,197	1.7	186,760	2.1	298,616	27.6	14,971	1.8	0	0.0	500,345	2.4
Cotton	16,858	5.6	560,237	6.4	12,369	1.1	51,108	6.1	0	0.0	623,746	3.0
Grass hay	14,596	4.9	445,865	5.1	87,698	8.1	47,426	5.6	0	0.0	580,989	2.8
Legume hay	24,776	8.3	444,358	5.1	18,299	1.7	65,268	7.8	4,512,759	43.4	5,040,690	24.0
Oats	3,772	1.3	43,934	0.5	852	0.1	9,303	1.1	0	0.0	54,096	0.3
Peanuts	1,843	0.6	17,372	0.2	1,629	0.2	7,207	0.9	63,490	0.6	89,699	0.4
Potatoes	987	0.3	72,952	0.8	1,315	0.1	2,268	0.3	0	0.0	76,535	0.4
Rice	3,637	1.2	190,001	2.2	7	<0.1	15,522	1.8	0	0.0	205,541	1.0
Spring wheat	20,503	6.9	423,081	4.9	4,206	0.4	32,545	3.9	0	0.0	459,961	2.2
Sorghum	10,897	3.7	444,695	5.1	16,465	1.5	27,978	3.3	0	0.0	489,144	2.3
Soybeans	67,543	22.6	143,954	1.7	59,224	5.5	221,487	26.3	5,823,836	56.0	6,248,524	29.7
Winter wheat	45,014	15.1	1,179,798	13.6	26,822	2.5	106,697	12.7	0	0.0	1,313,400	6.2
All crops	298,478	100.0	8,694,553	100.0	1,082,242	100.0	840,601	100.0	10,400,085	100.0	21,017,780	100.0

Map 13 Average annual commercial fertilizer application rates for nitrogen in model simulations



fertilizer interspersed among soybean acres receiving little to moderate commercial fertilizer. In some places, the application rates show sharp differences between neighboring states, revealing the state-level nature of the available farmer survey information.

Map 14 shows the spatial distribution of manure applications used for the model simulations. Class breaks used in map 14 were the same as used for map 13 to facilitate comparisons between manure and commercial fertilizer sources of nitrogen. The broad areas of intensive animal agriculture can be identified in map 14 by the higher application rates: swine production in Iowa and North Carolina; poultry production in the Mid-Atlantic area and parts of the Southeast; dairy production in the Northeast, in Minnesota, Wisconsin, and parts of Michigan, and in areas in California and parts of Texas; and fattened cattle production in the mid-Great Plains area and areas throughout the West. These hot spots for manure application correspond closely to areas of intensive livestock production reported by Kellogg et al. (2000).

The percentage of acres shown in the legend of map 14 for each application rate class is the percentage of NRI acres for which some portion of the acres at an NRI point received manure, not the percentage of acres treated with manure. In areas of intensive livestock production, the portion of acres at the NRI point receiving manure could be high, but in most other areas, it was low, often below 10 percent. Overall, only 3.6 percent of the acres included in the study received manure applications (table 19) in the model simulations. Also evident in map 14 are broad areas of cropland that received almost no manure applications.

The per-acre application rates for nitrogen from manure and nitrogen from commercial fertilizer presented in maps 13 and 14 (as well as application rates shown in tables) are the averages for all cropland acres, including acres without manure application or without commercial fertilizer application. The averages shown are thus lower than the application rates assigned to each crop as model inputs, such as those shown in tables 15 and 18. For example, the manure nitrogen application rates for corn in climate cluster 1 in Nebraska ranged from 146 to 342 pounds of nitrogen per acre for cropland acres associated with manure producing farms and ranged from 79 to 184 pounds of nitrogen per acre for cropland acres associated with manure receiving farms, depending on the yield class (table 18). However, only 5.3 percent of the total corn acres received manure in that state-climate cluster. The overall average manure nitrogen application rate for corn in the Nebraska portion of climate cluster 1 was about 10 pounds per acre, which is the value represented in map 14.

An important feature shown on both maps 13 and 14 is the variability in average nitrogen applications even within fairly localized areas.

Nitrogen input estimates by region

Northeast region. The highest per-acre nitrogen input was in the Northeast region (fig. 14, table 34), averaging 244 pounds of nitrogen per acre of cropland. About 65 percent of nitrogen inputs in this region were from bio-fixation (fig. 15), followed by 23 percent for commercial fertilizer, 9 percent for manure, and 3 percent for atmospheric deposition. The average rate for manure application was also highest in the Northeast (fig. 14), averaging 22 pounds of nitrogen per acre of cropland. This was largely due to 1.5 million acres of corn silage, which represented a third of the acreage of non-legume row crops in the Northeast and had an average application rate of 114 pounds of manure nitrogen per acre.

Upper Midwest region. The Upper Midwest region had the second-highest per acre nitrogen input, averaging 176 pounds per cropland acre (table 34). Nitrogen inputs in the Upper Midwest were disproportionately high, representing nearly half of the total nitrogen inputs for all regions but accounting for only 38 percent of the cropland acres (table 33). About 56 percent of the nitrogen inputs in this region was bio-fixation, 35 percent was commercial fertilizer, 5 percent was manure, and 4 percent was atmospheric deposition (fig. 15).

South Central and Southeast regions. Nitrogen inputs in the South Central region and the Southeast averaged 157 and 154 pounds per acre of cropland, respectively (fig. 14). The percent representation by source was similar to that in the Upper Midwest region, although, both regions received more nitrogen from atmospheric deposition and the Southeast received slightly more nitrogen from manure applications on a per-acre basis. Among all the regions, atmospheric deposition of nitrogen was highest in these two regions—averaging 8 to 9 pounds per acre—because of higher precipitation.

Map 14 Average annual manure nitrogen application rates in model simulations

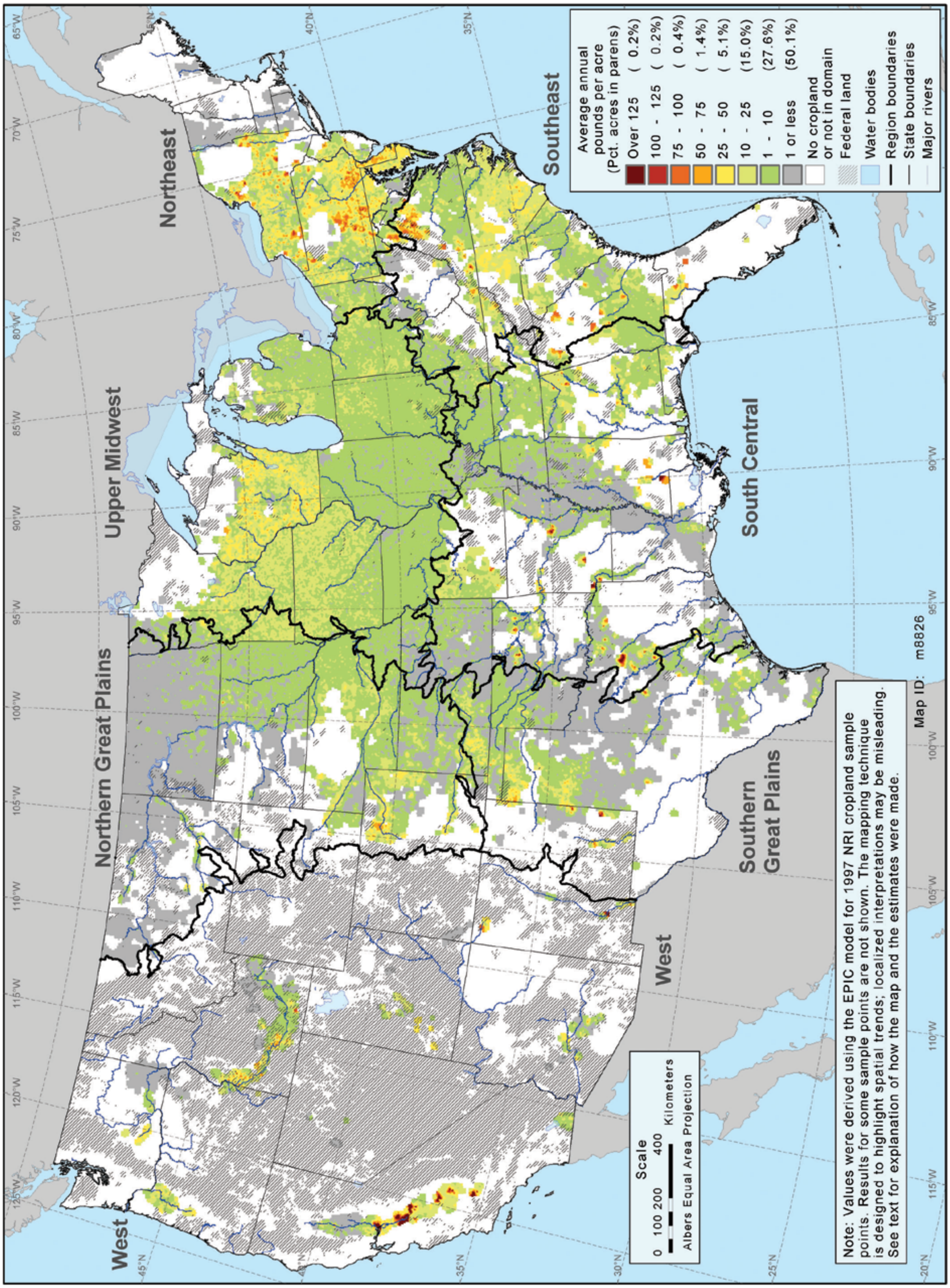


Figure 14 Sources of per-acre nitrogen inputs–by region

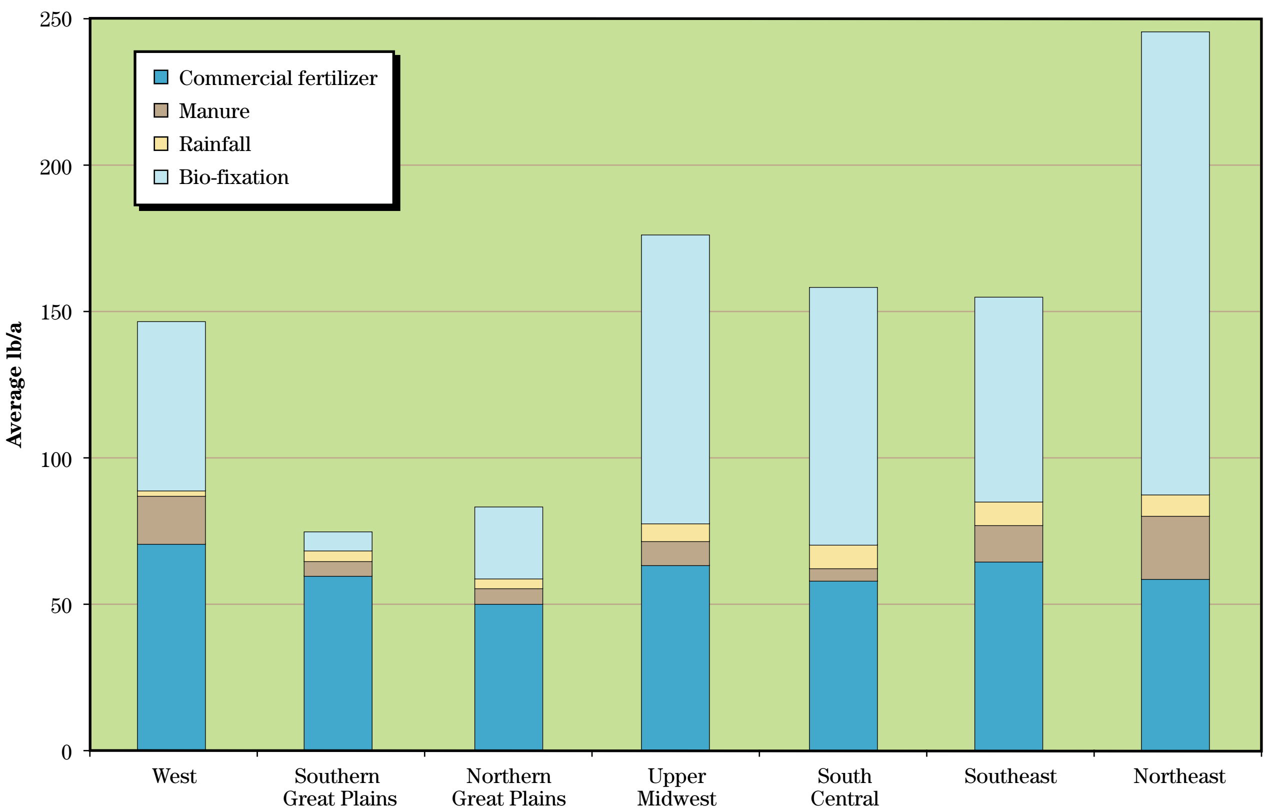


Table 34 Sources of nitrogen inputs on a per-acre basis–by region and by crop within regions (average annual values)

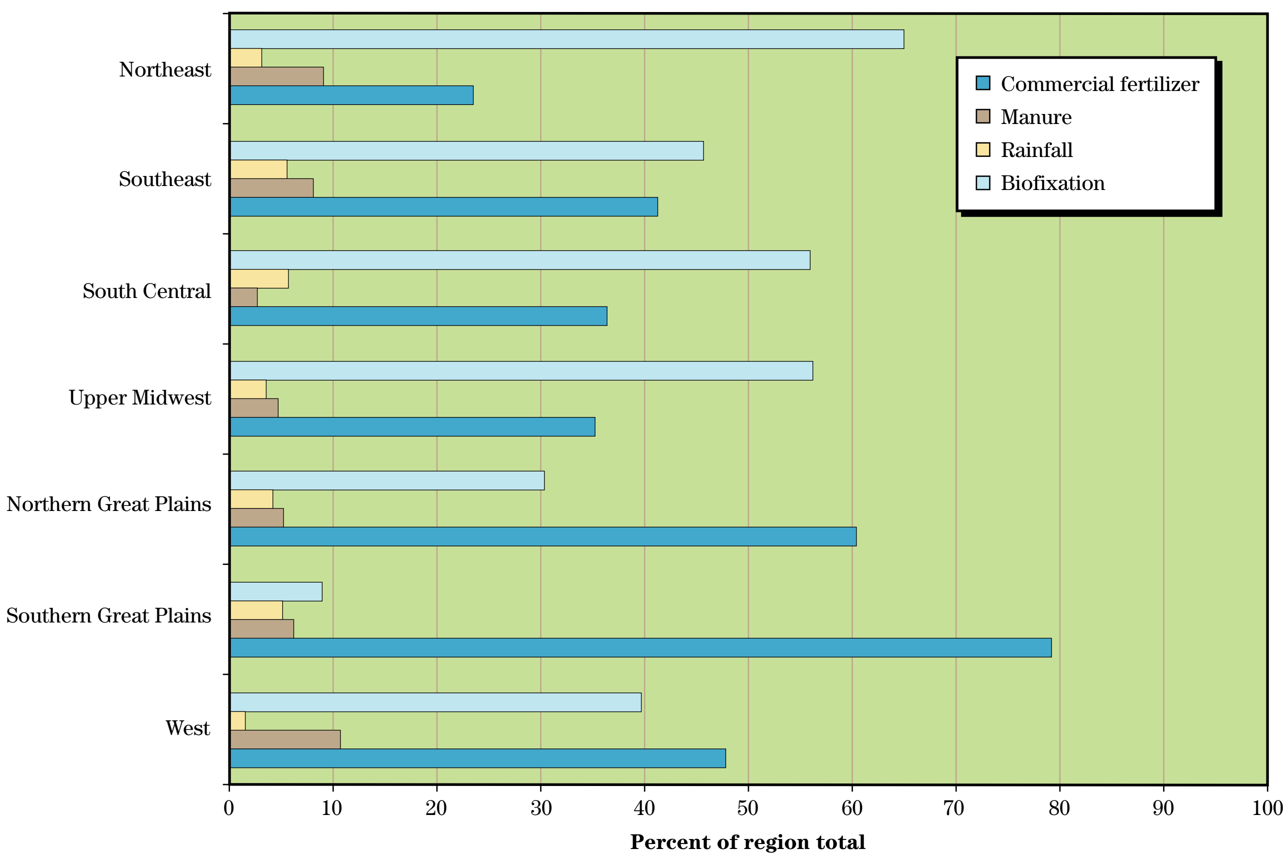
Region	Crop	Acres (1,000s)	Commercial fertilizer (lb/a)	Manure (lb/a)	Atmospheric deposition (lb/a)	Bio-fixation (lb/a)	Sum of inputs (lb/a)
By region							
Northeast	All crops	13,642	57.0	21.5	7.1	158.6	244.2
Northern Great Plains	All crops	72,397	50.1	4.3	3.4	25.1	82.9
South Central	All crops	45,350	56.9	3.8	8.7	87.9	157.3
Southeast	All crops	13,394	63.3	12.3	8.3	70.0	153.9
Southern Great Plains	All crops	32,096	59.4	4.6	3.8	6.6	74.5
Upper Midwest	All crops	112,581	62.3	8.3	6.1	99.1	175.8
West	All crops	9,018	70.7	15.9	2.3	58.4	147.3
All regions	All crops	298,478	58.3	7.3	5.6	69.7	141.0
By crop within region*							
Northeast	Corn	2,943	85.3	27.1	7.2	0.0	119.6
	Corn silage	1,482	64.5	113.7	7.0	0.0	185.2
	Grass hay	2,369	63.6	6.4	7.0	0.0	77.0
	Legume hay	4,052	35.9	0.9	6.9	485.1	528.9
	Oats	362	52.4	1.0	7.0	0.0	60.3
	Soybeans	1,305	31.7	16.8	7.5	151.3	207.4
	Winter wheat	853	53.3	3.4	7.4	0.0	64.1
Northern Great Plains	Barley	3,243	78.4	0.3	3.0	0.0	81.8
	Corn	15,466	101.2	13.7	3.7	0.0	118.6
	Corn silage	810	69.6	67.0	3.5	0.0	140.1
	Grass hay	2,443	64.5	3.4	3.2	0.0	71.1
	Legume hay	6,152	35.9	1.1	3.3	168.7	209.0
	Oats	1,255	17.9	0.1	3.3	0.0	21.3
	Spring wheat	18,916	39.0	0.0	3.1	0.0	42.1
	Sorghum	1,595	79.8	4.7	3.6	0.0	88.2
	Soybeans	9,562	2.9	1.0	3.7	81.4	89.0
	Winter wheat	12,748	34.9	0.7	3.3	0.0	38.9
South Central	Corn	5,956	125.1	7.4	9.1	0.0	141.7
	Cotton	5,487	81.1	0.4	9.4	0.0	90.9
	Grass hay	3,347	55.9	24.6	8.3	0.0	88.8
	Legume hay	1,630	35.8	0.8	8.2	533.3	578.1
	Peanuts	880	13.9	2.1	9.3	79.3	104.5
	Rice	3,004	121.1	0.0	9.7	0.0	130.8
	Sorghum	2,729	83.4	2.0	7.4	0.0	92.9
	Soybeans	14,083	4.7	1.4	9.1	216.4	231.6
	Winter wheat	7,896	57.5	0.3	7.4	0.0	65.1

Table 34 Sources of nitrogen inputs on a per-acre basis–by region and by crop within regions (average annual values)—Continued

Region	Crop	Acres (1,000s)	Commercial fertilizer (lb/a)	Manure (lb/a)	Atmospheric deposition (lb/a)	Bio-fixation (lb/a)	Sum of inputs (lb/a)
Southeast	Corn	3,028	121.9	16.3	8.3	0.0	146.6
	Corn silage	412	105.7	69.3	8.0	0.0	183.1
	Cotton	2,422	63.0	1.9	8.7	0.0	73.6
	Grass hay	2,000	58.5	19.1	8.1	0.0	85.7
	Legume hay	1,183	35.9	1.1	7.7	478.7	523.5
	Peanuts	479	13.5	2.9	8.9	77.6	102.8
	Soybeans	2,419	12.2	14.2	8.4	137.9	172.7
	Winter wheat	1,216	55.9	4.6	8.3	0.0	68.9
Southern Great Plains	Corn	2,665	116.1	36.4	3.8	0.0	156.3
	Cotton	7,316	43.5	0.2	3.6	0.0	47.3
	Legume hay	677	35.8	2.8	3.3	256.5	298.5
	Oats	503	16.8	0.4	4.9	0.0	22.0
	Peanuts	484	33.2	0.1	4.2	41.3	78.8
	Sorghum	4,895	81.0	3.4	4.0	0.0	88.4
	Winter wheat	15,037	53.2	1.0	3.9	0.0	58.0
Upper Midwest	Corn	47,941	114.2	12.6	6.2	0.0	133.0
	Corn silage	1,947	63.8	136.8	5.7	0.0	206.4
	Grass hay	4,044	64.4	4.0	6.1	0.0	74.6
	Legume hay	9,233	35.9	0.8	5.8	420.8	463.4
	Oats	1,388	18.9	0.3	5.6	0.0	24.8
	Spring wheat	815	81.3	0.2	4.9	0.0	86.4
	Sorghum	1,604	82.4	1.2	6.0	0.0	89.6
	Soybeans	40,049	3.0	0.8	6.2	181.6	191.7
	Winter wheat	5,147	82.5	0.2	6.3	0.0	89.1
West	Barley	958	60.2	2.5	2.2	0.0	64.8
	Corn silage	297	78.1	202.1	2.6	0.0	282.9
	Cotton	1,631	125.4	10.2	1.8	0.0	137.5
	Legume hay	1,847	35.5	7.5	1.8	285.2	330.1
	Potatoes	329	214.4	3.1	1.9	0.0	219.4
	Rice	599	22.8	0.0	3.1	0.0	25.9
	Spring wheat	772	55.7	10.5	2.1	0.0	68.3
	Winter wheat	2,118	58.4	8.4	2.8	0.0	69.6

* Estimates for crops with less than 250,000 acres within a region are not shown. However, acres for these minor crops are included in the calculation of the regional estimates.

Figure 15 Sources of nitrogen inputs as a percent of the regional total



Northern Great Plains and Southern Great Plains. On a per-acre basis, nitrogen inputs were lowest for the Northern Great Plains and Southern Great Plains regions for almost all sources (fig. 14, table 34), averaging 83 and 75 pounds of nitrogen per acre, respectively. This was largely because of the small acreage of nitrogen bio-fixing legume crops. Commercial fertilizer accounted for the bulk of the nitrogen inputs in these two regions (fig. 15); manure nitrogen and atmospheric deposition each accounted for about 5 percent of the total inputs.

West region. Total nitrogen input for the West region averaged 147 pounds per acre (table 34, fig. 14). The largest source was commercial fertilizer at 48 percent, followed by bio-fixation at 40 percent, manure at 11 percent, and atmospheric deposition at 1.6 percent (fig. 15). The West region had the lowest amount of nitrogen from atmospheric deposition, averaging only 2.3 pounds per acre in these model simulations.

Nitrogen input estimates by crop

Of all the crops, alfalfa hay had the highest per-acre amount of nitrogen inputs in these model simulations, mostly consisting of bio-fixation (fig. 16, table 34). Corn silage and soybeans were the next highest. Nitrogen for soybeans was almost entirely bio-fixation, whereas manure was the dominant source for corn silage. Commercial nitrogen fertilizer application rates varied from crop to crop, with the highest rates for potatoes, rice, and corn, and the lowest for soybeans (fig. 16). Commercial nitrogen fertilizer accounted for 80 percent or more of the nitrogen inputs for all but corn silage and the three legume crops. About 60 percent of the nitrogen sources for corn silage came from manure. Manure was a significant source on a per-acre basis for only three crops—corn silage, corn, and grass hay—resulting directly from assumptions used to derive the manure application database.

Model simulation results for nitrogen loss

Of the 21 million tons per year of nitrogen inputs represented in the EPIC model simulations, about 28 percent—6 million tons—was lost from the field through volatilization, dissolved in surface water runoff, leaching, or carried away with the soil by wind and water erosion (table 35). Most nitrogen was lost through volatilization—47 percent, equivalent to an average per acre loss of 18.5 pounds per year. The next highest loss pathway, accounting for 21 percent of total nitrogen loss, was nitrogen lost with waterborne sediment, which averaged 8.5 pounds per cropland acre per year (table 35, table 23). Nitrogen dissolved in leachate was the third highest loss category, averaging 6.7 pounds per acre per year and representing 17 percent of total nitrogen losses. Nitrogen dissolved in surface water runoff averaged 3.8 pounds per acre per year and accounted for 10 percent of total nitrogen loss. On average for all cropland, windborne nitrogen loss with sediment accounted for about 4 percent of nitrogen loss, and nitrogen lost from the field through lateral subsurface flow accounted for only about 1 percent. The average for all nitrogen loss pathways combined was about 40 pounds per acre per year (table 36).

Map 15 shows the distribution of the sum of nitrogen loss from all six pathways. The most vulnerable areas for overall loss of nitrogen from farm fields are colored red and brown in the map, and represent about 9 percent of the cropland acres. In these areas, the loss of nitrogen from farm fields averages over 72 pounds per acre per year. These highly vulnerable cropland acres are scattered throughout various parts of the country, but tend to be concentrated mostly in Iowa, Indiana, Pennsylvania, the Atlantic Coastal Plain, Lower Mississippi River Basin, and southeastern Texas. The least vulnerable acres, represented in green on the map, comprise 59 percent of the cropland acres and have total nitrogen loss rates below 36 pounds per acre per year, on average.

The potential for nitrogen loss varied considerably among cropland acres, reflecting variability in the amounts lost through each of the six nitrogen loss pathways, variability in nitrogen lost among soils with different properties, variability in the amount and kind of nitrogen sources by crop, the extent to which conservation tillage occurred, and the extent to which the three conservation practices included in the model simulation were present.

Per-acre nitrogen loss estimates for six loss pathways

The spatial distribution of nitrogen loss for each of the nitrogen loss pathways (except lateral subsurface flow) is shown in maps 16 through 20. The class breaks for maps 16 through 20 are the same so that comparisons can be made among the maps. It is clear from these maps that there is considerable variability within cropland as to which loss pathways account

Figure 16 Sources of per-acre nitrogen inputs–by crop

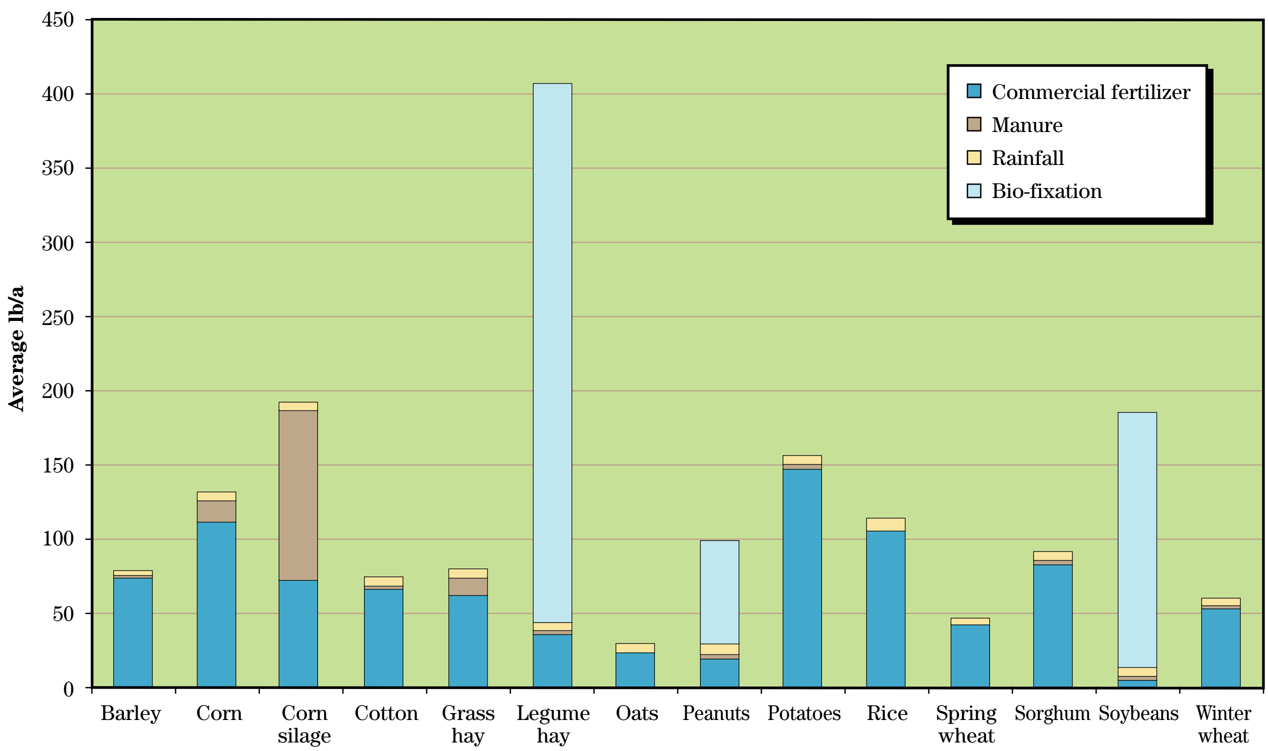


Table 35 Nitrogen loss estimates–by region and by crop (annual average values)

	Acres	Volatilized		Dissolved in surface water runoff		Dissolved in leachate		Dissolved in lateral subsurface flow		Lost with waterborne sediment		Lost with windborne sediment		Sum of all loss pathways	
	Percent	Tons	Percent	Tons	Percent	Tons	Percent	Tons	Percent	Tons	Percent	Tons	Percent	Tons	Percent
By region															
Northeast	4.6	78,711	2.9	45,275	7.9	46,457	4.7	4,604	7.0	91,141	7.2	1,060	0.4	267,281	4.5
Northern Great Plains	24.3	596,583	21.6	64,928	11.4	36,852	3.7	11,222	17.0	164,394	12.9	131,371	49.4	1,005,360	17.0
South Central	15.2	398,622	14.5	174,590	30.6	304,219	30.5	11,747	17.8	247,942	19.5	9,657	3.6	1,146,779	19.3
Southeast	4.5	170,688	6.2	26,587	4.7	200,291	20.1	5,934	9.0	47,604	3.7	86	<0.1	451,191	7.6
Southern Great Plains	10.8	438,673	15.9	27,384	4.8	61,394	6.1	4,089	6.2	41,002	3.2	103,231	38.8	675,785	11.4
Upper Midwest	37.7	996,009	36.1	159,552	28.0	339,126	34.0	27,060	41.0	665,135	52.4	19,473	7.3	2,206,378	37.2
West	3.0	76,795	2.8	72,026	12.6	10,298	1.0	1,399	2.1	12,301	1.0	1,047	0.4	173,956	2.9
All regions	100.0	2,756,079	100.0	570,341	100.0	998,637	100.0	66,055	100.0	1,269,517	100.0	265,924	100.0	5,926,729	100.0
By crop															
Barley	1.6	52,993	1.9	12,562	2.2	1,765	0.2	1,235	1.9	11,585	0.9	6,659	2.5	86,798	1.5
Corn	26.2	956,074	34.7	124,161	21.8	389,473	39.0	25,796	39.1	562,179	44.3	92,247	34.7	2,149,929	36.3
Corn silage	1.7	46,467	1.7	15,244	2.7	20,805	2.1	2,448	3.7	56,684	4.5	5,058	1.9	146,705	2.5
Cotton	5.6	101,326	3.7	55,777	9.8	114,922	11.5	2,574	3.9	51,654	4.1	48,920	18.4	375,172	6.3
Grass hay	4.9	59,044	2.1	66,011	11.6	4,287	0.4	1,660	2.5	13,986	1.1	34	<0.1	145,023	2.4
Legume hay	8.3	152,594	5.5	67,735	11.9	5,340	0.5	2,555	3.9	781	0.1	13	<0.1	229,193	3.9
Oats	1.3	18,264	0.7	3,289	0.6	4,435	0.4	512	0.8	14,784	1.2	2,515	0.9	43,797	0.7
Peanuts	0.6	16,915	0.6	3,124	0.5	40,268	4.0	1,637	2.5	3,957	0.3	2,455	0.9	68,355	1.2
Potatoes	0.3	20,253	0.7	8,181	1.4	21,245	2.1	785	1.2	4,006	0.3	1,710	0.6	56,178	0.9
Rice	1.2	11,869	0.4	60,612	10.6	39,659	4.0	177	0.3	13,268	1.0	60	<0.1	125,643	2.1
Spring wheat	6.9	129,671	4.7	21,068	3.7	1,248	0.1	1,666	2.5	48,548	3.8	29,990	11.3	232,189	3.9
Sorghum	3.7	147,017	5.3	10,851	1.9	30,979	3.1	2,495	3.8	36,176	2.8	34,269	12.9	261,785	4.4
Soybeans	22.6	581,091	21.1	90,757	15.9	282,995	28.3	17,786	26.9	352,233	27.7	24,865	9.4	1,349,726	22.8
Winter wheat	15.1	462,504	16.8	30,973	5.4	41,217	4.1	4,733	7.2	99,679	7.9	17,133	6.4	656,238	11.1
All crops	100.0	2,756,079	100.0	570,341	100.0	998,637	100.0	66,055	100.0	1,269,517	100.0	265,924	100.0	5,926,729	100.0

Table 36 Nitrogen loss estimates on a per-acre basis–by region and by crop within regions (average annual values)

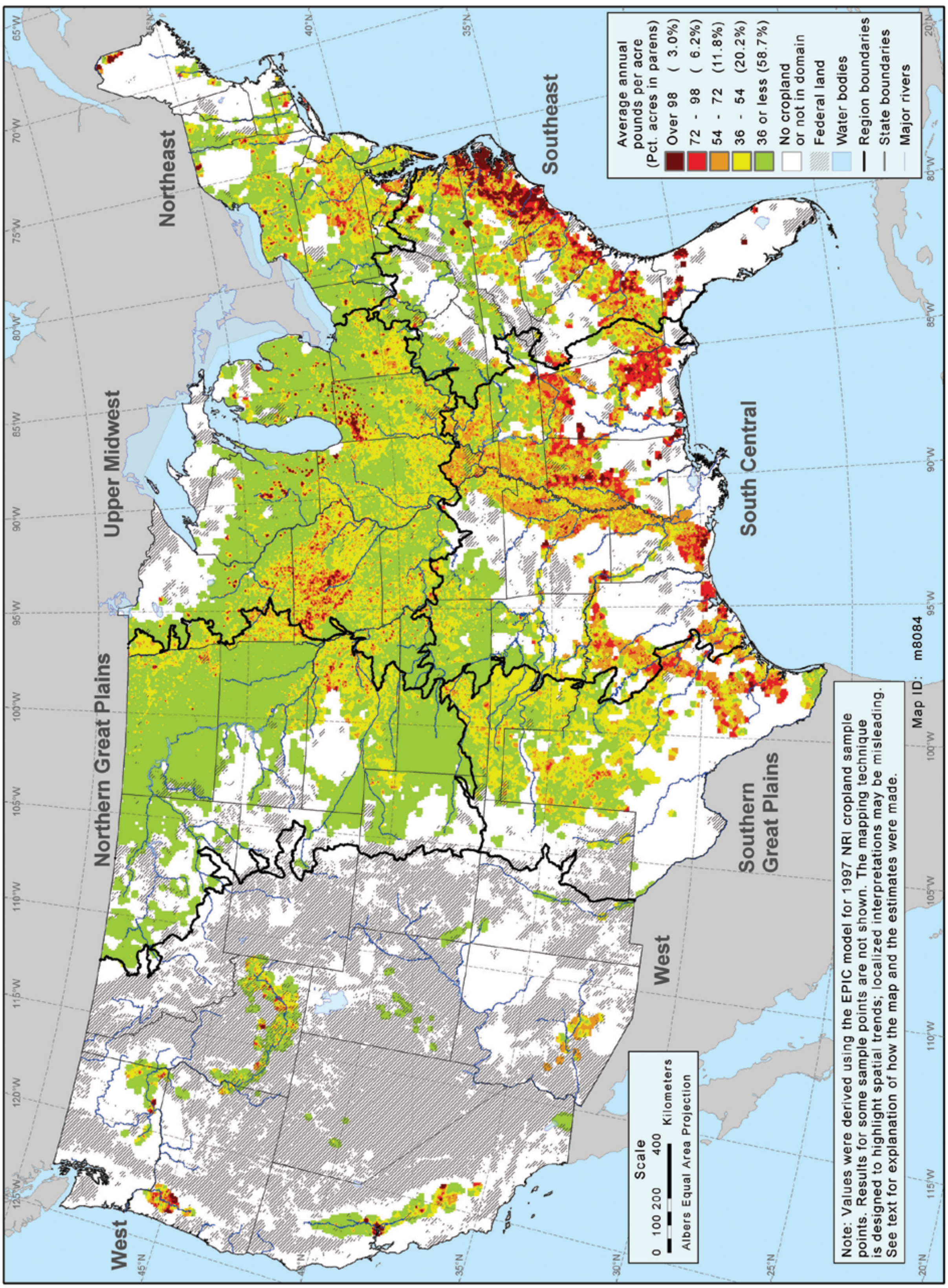
Region	Crop	Acres (1,000s)	Volatilized (lb/a)	Dissolved in surface water runoff (lb/a)	Dissolved in leachate (lb/a)	Dissolved in lateral subsurface flow (lb/a)	Lost with waterborne sediment (lb/a)	Lost with windborne sediment (lb/a)	Sum of all loss pathways (lb/a)
By region									
Northeast	All crops	13,642	11.5	6.6	6.8	0.7	13.4	0.2	39.2
Northern Great Plains	All crops	72,397	16.5	1.8	1.0	0.3	4.5	3.6	27.8
South Central	All crops	45,350	17.6	7.7	13.4	0.5	10.9	0.4	50.6
Southeast	All crops	13,394	25.5	4.0	29.9	0.9	7.1	<0.1	67.4
Southern Great Plains	All crops	32,096	27.3	1.7	3.8	0.3	2.6	6.4	42.1
Upper Midwest	All crops	112,581	17.7	2.8	6.0	0.5	11.8	0.3	39.2
West	All crops	9,018	17.0	16.0	2.3	0.3	2.7	0.2	38.6
All regions	All crops	298,478	18.5	3.8	6.7	0.4	8.5	1.8	39.7
By crop within region*									
Northeast	Corn	2,943	12.6	3.2	11.8	0.9	23.3	0.3	52.1
	Corn silage	1,482	10.4	5.4	8.5	1.2	40.9	0.4	66.9
	Grass hay	2,369	6.8	15.5	0.8	0.3	4.2	<0.1	27.5
	Legume hay	4,052	13.5	7.0	1.3	0.4	0.1	<0.1	22.2
	Oats	362	8.1	4.3	4.7	0.7	17.7	0.1	35.7
	Soybeans	1,305	13.8	2.9	17.4	1.0	13.3	0.3	48.6
	Winter wheat	853	11.5	2.3	1.9	0.4	15.2	0.1	31.2
Northern Great Plains	Barley	3,243	26.7	3.2	0.2	0.5	4.7	3.9	39.1
	Corn	15,466	28.2	2.7	3.6	0.8	8.0	7.7	50.9
	Corn silage	810	20.3	3.1	2.3	0.7	9.0	7.7	43.1
	Grass hay	2,443	5.3	6.6	<0.1	0.1	0.4	<0.1	12.4
	Legume hay	6,152	12.0	3.0	0.1	0.1	0.1	<0.1	15.2
	Oats	1,255	8.8	0.7	0.2	0.2	5.2	3.3	18.3
	Spring wheat	18,916	12.6	1.4	0.1	0.2	4.8	3.1	22.1
	Sorghum	1,595	26.3	1.4	1.4	0.7	6.0	7.7	43.5
	Soybeans	9,562	13.3	0.5	0.7	0.2	5.7	3.7	24.2
	Winter wheat	12,748	10.9	0.4	0.1	0.1	1.5	0.9	14.0
South Central	Corn	5,956	18.3	8.4	13.1	0.7	19.1	0.6	60.2
	Cotton	5,487	9.0	5.1	20.7	0.4	12.4	0.1	47.6
	Grass hay	3,347	9.3	4.8	0.6	0.2	2.1	<0.1	17.0
	Legume hay	1,630	10.8	3.2	0.4	0.2	0.1	<0.1	14.8
	Peanuts	880	18.9	2.8	50.2	2.2	4.8	0.6	79.6
	Rice	3,004	6.9	37.8	24.5	0.1	8.6	<0.1	77.9
	Sorghum	2,729	17.4	2.8	8.5	0.4	11.1	2.6	42.8
	Soybeans	14,083	25.1	7.8	17.4	0.7	12.4	0.4	63.8
	Winter wheat	7,896	18.7	1.9	2.9	0.3	8.4	0.2	32.4

Table 36 Nitrogen loss estimates on a per-acre basis–by region and by crop within regions (average annual values)—Continued

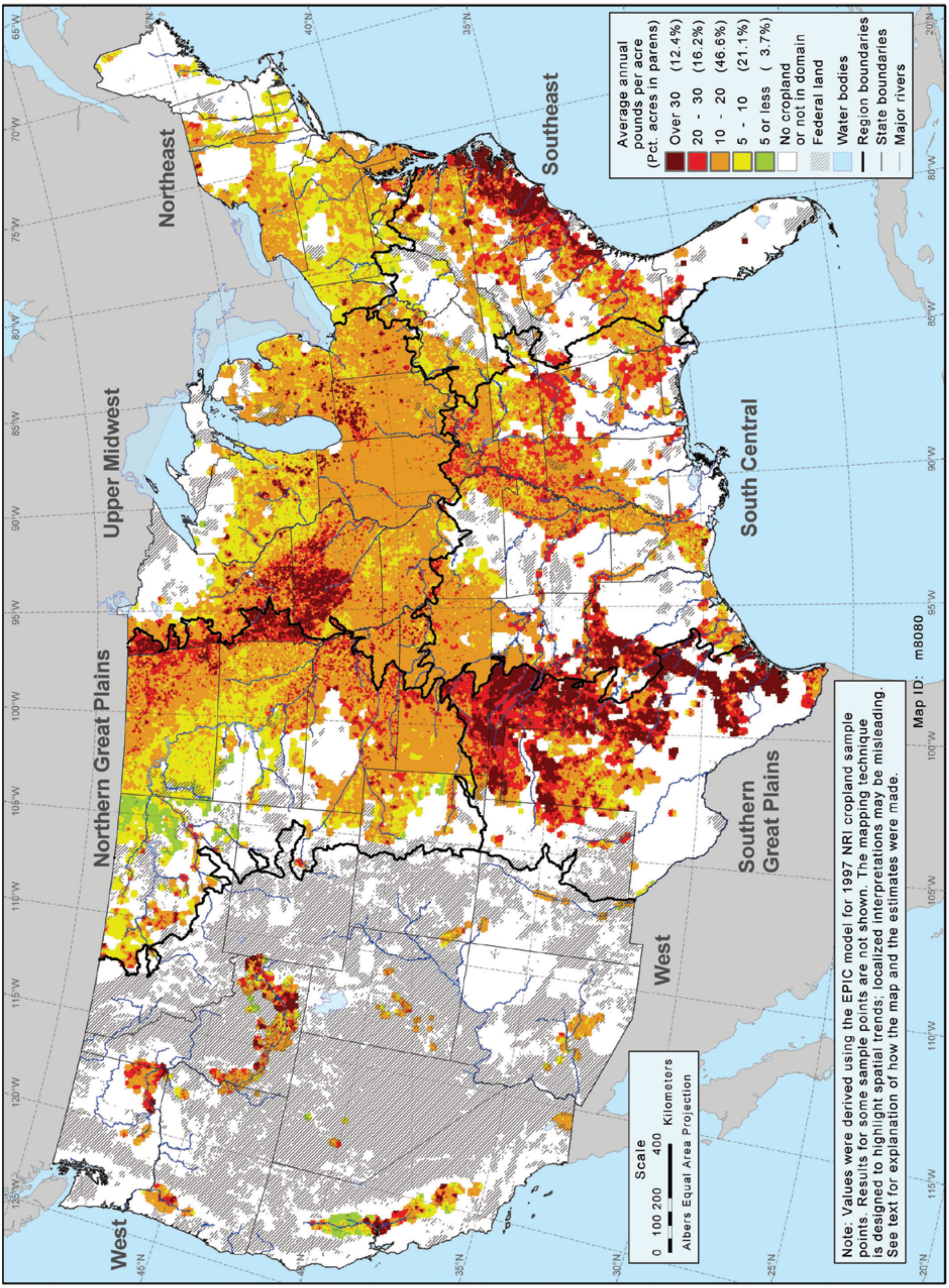
Region	Crop	Acres (1,000s)	Volatilized (lb/a)	Dissolved in surface water runoff (lb/a)	Dissolved in leachate (lb/a)	Dissolved in lateral subsurface flow (lb/a)	Lost with waterborne sediment (lb/a)	Lost with windborne sediment (lb/a)	Sum of all loss pathways (lb/a)
Southeast	Corn	3,028	45.6	5.0	51.0	1.1	12.5	<0.1	115.2
	Corn silage	412	22.4	6.6	18.3	1.7	20.4	<0.1	69.5
	Cotton	2,422	10.7	2.1	26.6	0.6	5.6	<0.1	45.7
	Grass hay	2,000	12.4	5.5	2.2	0.3	2.5	<0.1	22.9
	Legume hay	1,183	12.5	5.2	1.6	0.4	0.1	<0.1	19.8
	Peanuts	479	18.4	2.7	55.5	1.8	5.4	<0.1	83.8
	Soybeans	2,419	31.3	3.4	41.6	1.4	5.8	<0.1	83.6
	Winter wheat	1,216	33.1	2.2	23.1	0.7	9.8	<0.1	68.8
Southern Great Plains	Corn	2,665	30.4	5.6	4.3	0.4	4.9	12.4	57.9
	Cotton	7,316	14.5	2.1	6.5	0.2	2.9	13.3	39.4
	Legume hay	677	15.4	3.7	0.1	0.1	<0.1	<0.1	19.2
	Oats	503	20.8	1.4	6.2	0.3	3.3	0.6	32.6
	Peanuts	484	17.3	5.0	20.1	1.0	2.3	9.1	54.8
	Sorghum	4,895	36.6	1.8	5.9	0.3	3.1	9.9	57.5
	Winter wheat	15,037	31.5	0.5	1.4	0.2	1.9	1.3	37.0
Upper Midwest	Corn	47,941	23.0	2.3	9.3	0.6	16.0	0.6	51.7
	Corn silage	1,947	19.3	3.2	7.5	0.8	16.6	0.7	48.0
	Grass hay	4,044	7.2	12.8	0.1	0.2	1.2	<0.1	21.5
	Legume hay	9,233	11.0	7.6	0.2	0.2	<0.1	<0.1	19.1
	Oats	1,388	6.7	1.1	0.8	0.2	9.0	0.4	18.2
	Spring wheat	815	17.5	5.4	0.1	0.1	5.5	0.8	29.5
	Sorghum	1,604	15.4	1.6	4.1	0.6	10.6	0.4	32.8
	Soybeans	40,049	14.6	1.4	4.8	0.5	11.1	0.2	32.5
	Winter wheat	5,147	14.8	3.1	0.6	0.2	8.9	0.1	27.8
West	Barley	958	14.8	13.5	0.8	0.8	4.8	0.5	35.2
	Corn silage	297	30.4	29.6	8.8	0.4	2.7	0.2	72.2
	Cotton	1,631	13.0	38.9	2.8	0.1	0.4	<0.1	55.3
	Legume hay	1,847	17.4	2.4	0.1	<0.1	0.1	<0.1	20.1
	Potatoes	329	56.1	38.7	10.0	2.1	0.6	1.4	108.9
	Rice	599	3.9	11.9	6.7	<0.1	1.0	<0.1	23.5
	Spring wheat	772	9.0	15.6	0.7	0.4	3.3	0.5	29.5
	Winter wheat	2,118	17.9	6.0	1.7	0.2	6.6	0.3	32.7

* Estimates for crops with less than 250,000 acres within a region are not shown. However, acres for these minor crops are included in the calculation of the regional estimates.

Map 15 Estimated average annual per-acre nitrogen loss summed over all loss pathways



Map 16 Estimated average annual per-acre nitrogen lost to the atmosphere



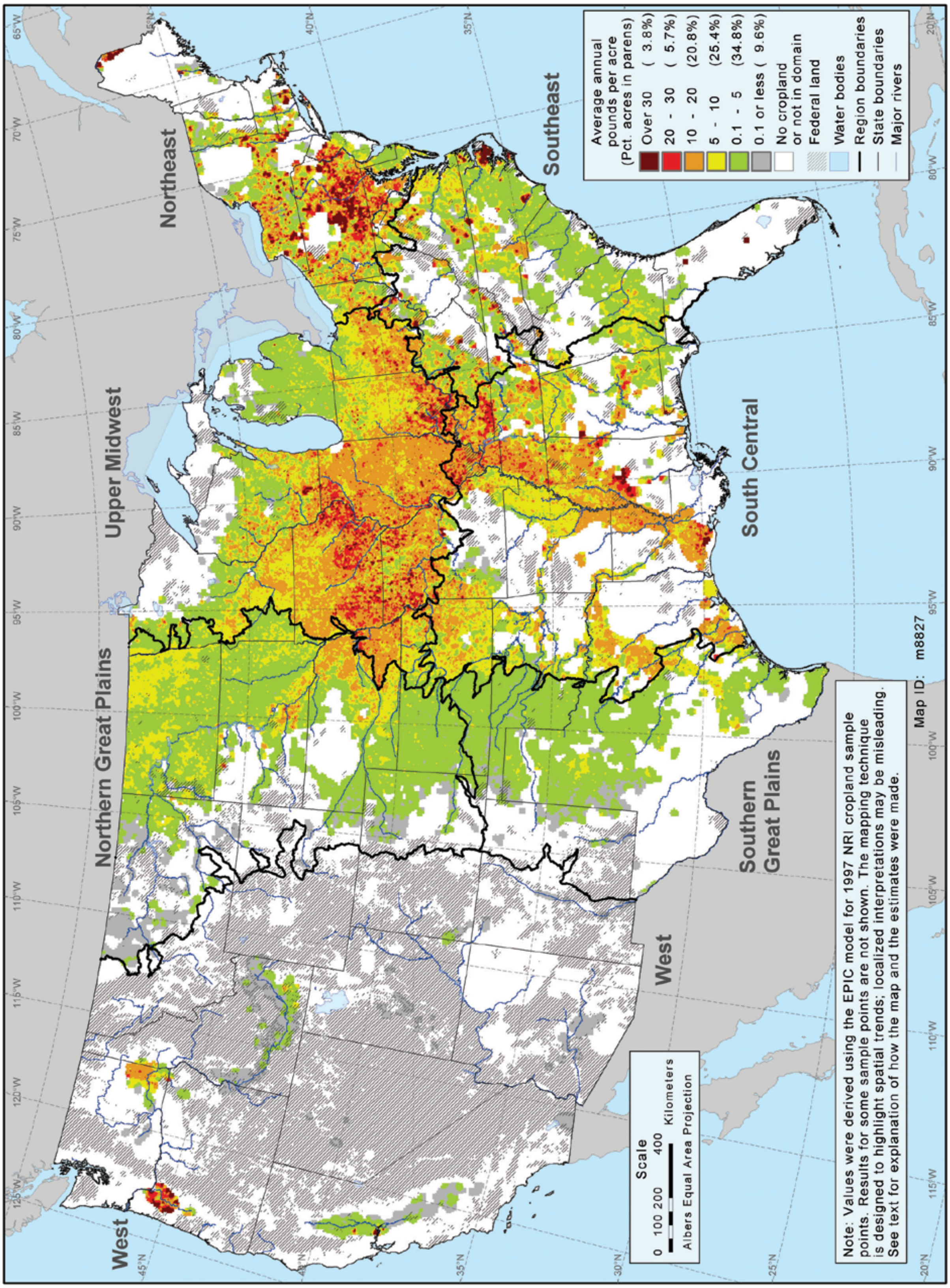
Geographic boundaries are sometimes evident on maps

Geographic boundaries such as state boundaries or climate zone boundaries are sometimes evident on the maps of model output. The sharp boundaries are not real, but rather are a modeling artifact. They are due to the use of highly aggregated input data on nutrient applications or due to adjacent climate zones with very different weather parameters. For example, several state boundaries and climate zone boundaries are evident in maps 15 and 16. There are sharp differences shown in model output along the state border between Minnesota and bordering states to the west. Climate zone boundary effects occur in parts of Nebraska, Kansas, and Texas. These boundary effects show up in other maps, as well.

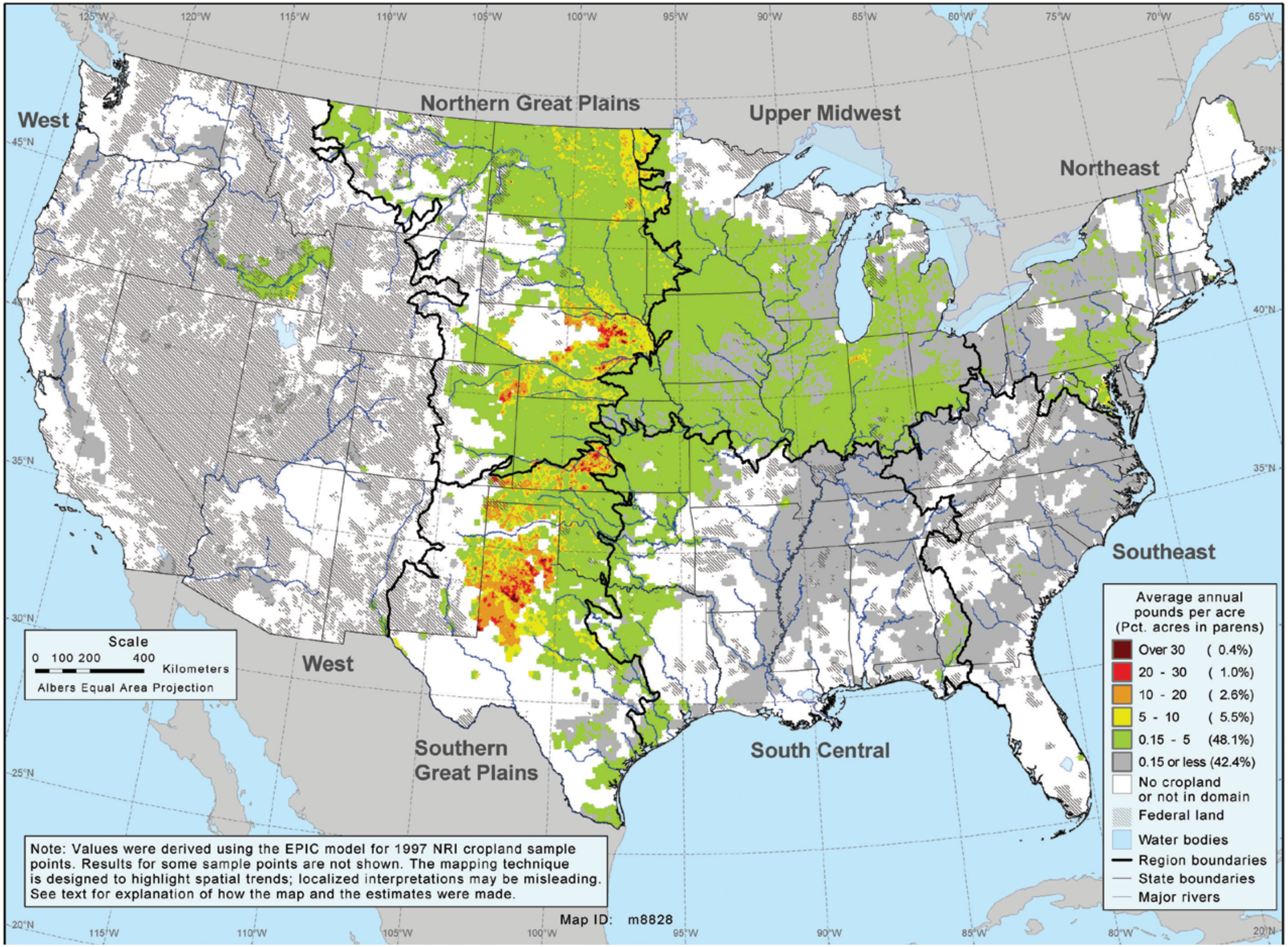
The origin of the state boundary effects is evident from the maps on nitrogen and phosphorus commercial fertilizer and manure application rates (see maps 13–14 and 26–27). Commercial fertilizer application data were derived from farmer surveys and aggregated to the state level or sometimes combinations of states for each crop. Manure application data were derived from the Census of Agriculture farm-level data and aggregated to the state-climate zone level for each crop. Thus, all NRI sample points for a particular crop in a particular state-climate zone area were modeled with the same average nutrient application inputs, which were sometimes markedly different from average nutrient application inputs in an adjoining state.

The origin of the climate zone boundaries is evident from the climate zone map (map 4). Most of the climate zones outside of the West region are very large, creating marked differences between climate zones in the data inputs used in the EPIC model to calculate precipitation (map 5) and surface water runoff (map 7). These climate zones boundaries are sometimes apparent in maps of model output heavily influenced by surface water runoff. The map of nitrogen lost with waterborne sediment (map 17), for example, shows climate zone boundary effects in the Great Plains regions.

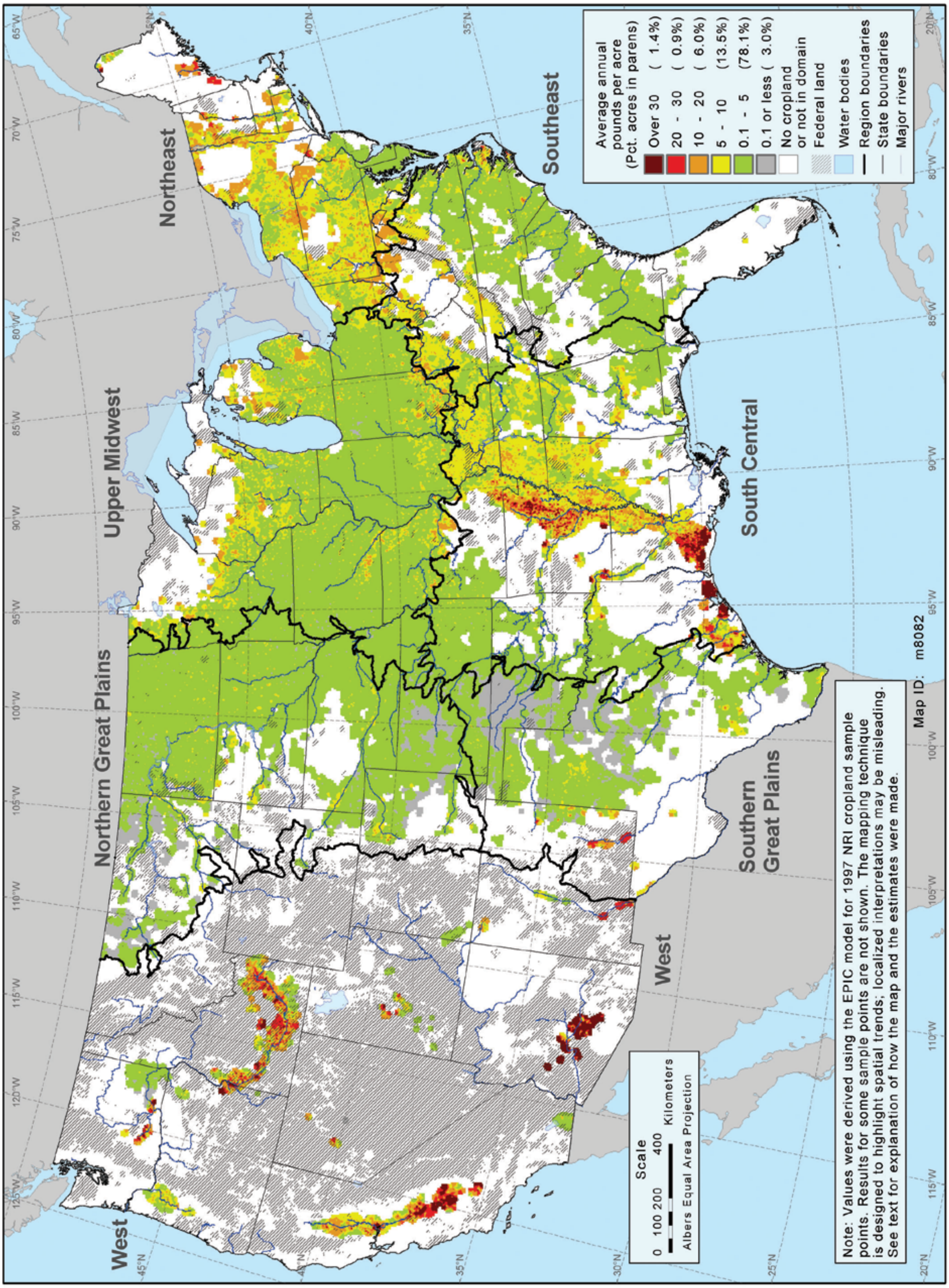
Map 17 Estimated average annual per-acre nitrogen lost with waterborne sediment



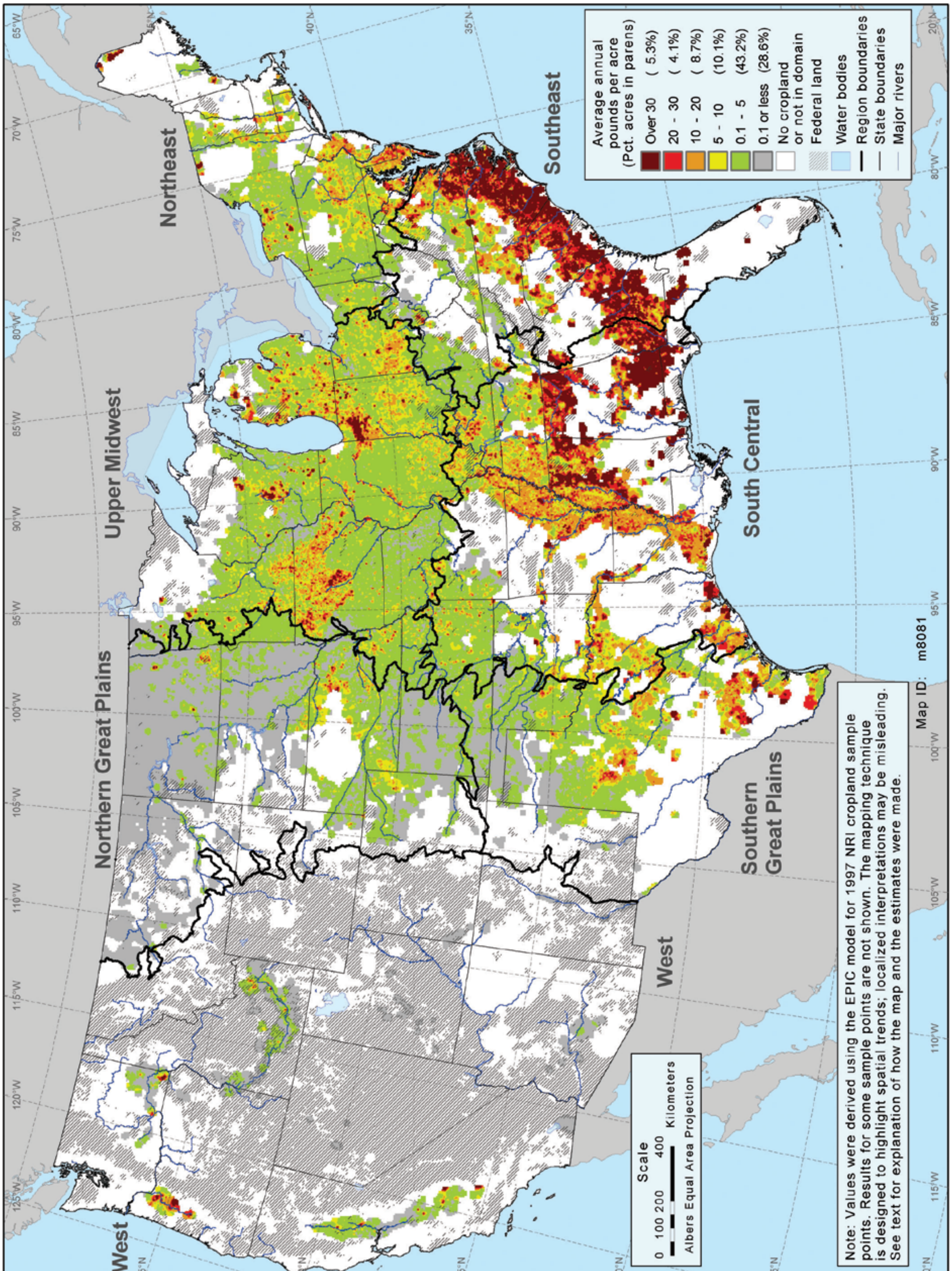
Map 18 Estimated average annual per-acre nitrogen lost with windborne sediment



Map 19 Estimated average annual per-acre nitrogen dissolved in surface water runoff



Map 20 Estimated average annual per-acre nitrogen dissolved in leachate



Visual distortion of cropland acres in per-acre maps

The mapping technique used to display per-acre model output results was developed specifically to show spatial trends, thereby identifying cropland areas with specific resource concerns. There are three steps involved in the mapping technique (see figs. 5 and 6):

Step 1. Calculate the average value for each 25-square kilometer (9.6 mi^2) grid cell using the model output for each NRI sample point located in the grid cell.

Step 2. Interpolate values to surrounding cells that have no NRI sample points.

Step 3. Perform a geographic transformation that smoothes the representation of the results.

While these steps enhance spatial trends, they also produce some distortion of the extent to which cropland acres are represented.

The biggest source of distortion stems from use of grid cells to represent NRI attributes. Some grid cells contain only a few NRI sample points, representing only a few acres of cropland. This is common in areas of the country where cropland is not the dominant land use. In areas where cropland is concentrated, each grid cell will represent many more cropland acres. Since all grid cells are the same size, this has the visual effect of exaggerating the cropland representation in some areas of the country relative to other areas of the country. Areas where cropland is a small share of the land use on the landscape appear over-represented in the maps.

Map 20 provides an example of this kind of distortion. The Atlantic Coastal Plain shows prominently on the map as a large area of high vulnerability to nitrogen dissolved in leachate. Most mapping cells in this area had average per acre values of over 30 pounds per acre—the highest class shown on the map. While cropland acres in this area are highly vulnerable to nitrogen leaching, less than 40 percent of the acres in that area are cropland acres. Overall, only 5.3 percent of the cropland acres included in the study had nitrogen leaching estimates above 30 pounds per acre, as shown in the legend for map 20. The visual representation leaves the impression that many more acres are vulnerable than there actually were.

The interpolation step further exaggerates the representation of cropland acres in areas of the map where cropland is a minor land use. This source of distortion is explained in figure 7. The visual impression of the extent of the vulnerable acres in the Atlantic Coastal Plain in map 20 is also affected by interpolation along the edges of the cropland areas.

The percentage of acres associated with the class breaks used to construct the maps is reported in the map legend to provide a perspective on the extent of the over-representation of acres in the maps. These percentages were calculated on the basis of the individual NRI sample points, and not on the basis of the average values for the map cells. Thus, the percentages reported in the map legend do not account for the "averaging effect" originating from use of the mean values to represent model output for each map cell.

for the bulk of the nitrogen loss in a particular area or even an entire region. This variability stems from the spatial variability among the various factors that effect nitrogen loss. Areas of greatest vulnerability did not always correspond to areas with the highest nitrogen inputs (maps 13 and 14), indicating the importance of the physical setting in nutrient loss dynamics.

Nitrogen volatilization. Loss of nitrogen to the atmosphere through volatilization was high for nearly all cropland acres (map 16), and was the highest loss pathway for the vast majority of acres. On the basis of model simulation results shown in map 16, the regions of greatest vulnerability for nitrogen volatilization—colored brown and red—are:

- A broad area in Oklahoma and Texas, which includes most of the cropland in those two states. In this area, volatilization losses appear to result from the prevalence of calcareous alkaline soils, high temperatures, strong winds, and lengthy dry periods. In the model simulations, fertilizers were applied according to a set activity schedule and were not adjusted to reflect dry periods and associated periods of depressed crop growth, which might partly explain the high nitrogen volatilization results obtained with EPIC for this area.
- An area that extends from northern Iowa northward through most of the cropland in Minnesota
- An area along the Mid-Atlantic coast that includes North Carolina and parts of South Carolina
- Cropland acres in the northwest

These vulnerable areas represent about 29 percent of cropland acres included in the study. The least vulnerable areas are colored yellow and green in the map and represent about 25 percent of cropland acres.

Nitrogen lost with waterborne sediment. In general, areas of greatest vulnerability for nitrogen lost with waterborne sediment are about the same as those shown for sediment loss in map 9. Areas of greatest vulnerability—colored brown and red in map 17—represent about 10 percent of the cropland acres included in the study. The area that stands out as the most vulnerable is in Pennsylvania and northern Maryland. An area consisting of cropland acres in Iowa, northern Missouri, and Illinois was also prominent in terms of vulnerable acres for nitrogen lost with waterborne sediment. This area was less prominent in terms of vulnerable acres for sediment loss.

Nitrogen lost with windborne sediment. Areas of greatest vulnerability for nitrogen lost with windborne sediment (map 18) are the same areas that had the highest potential for wind erosion shown in map 11.

Nitrogen dissolved in surface water runoff. The potential for loss of nitrogen dissolved in surface water runoff from farm fields is shown in map 19. For most cropland acres, the per-acre amount of nitrogen dissolved in surface water runoff was much less than nitrogen lost with waterborne sediment. About 78 percent of the cropland acres included in the study—colored green in map 19—had less than 5 pounds per acre of nitrogen dissolved in surface water runoff. Overall, the cropland areas with the highest potential for loss of nitrogen dissolved in surface water runoff—colored brown, red, and orange in the map and representing about 8 percent of the cropland acres included in the study—are:

- intensively irrigated areas in the West
- cropland acres in the lower Mississippi River Basin and the rice growing area that extends into southern Louisiana and southeastern Texas
- Northeast region
- northern edge of cropland in Minnesota, Wisconsin, and Michigan

In general, cropland areas with the highest loss of nitrogen dissolved in surface water runoff correspond to cropland acres with the highest surface water runoff shown in map 7.

Nitrogen dissolved in leachate. The spatial distribution for nitrogen dissolved in leachate (map 20) is quite different from the spatial patterns of nitrogen dissolved in surface water runoff. The spatial distribution generally corresponds to spatial trends in annual percolation. Most of the cropland acres in regions where percolation exceeds 5 inches per year are associated with elevated levels of nitrogen dissolved in leachate. A notable exception, however, is for a large region in northern Iowa where annual percolation rates are low but where loss of nitrogen in leachate is sometimes high. Intensively irrigated areas in the West and most cropland in the Great Plains have very low losses of nitrogen dissolved in leachate and also have low levels of percolation. The cropland area of highest percolation in the Southeast, extending from Alabama through Delaware, also has the highest loss of nitrogen dissolved in leachate in the country, usually exceeding rates of 30 pounds per acre per year. Cropland acres with the highest potential for nitrogen dissolved in leachate, represented by the brown and red colored areas in map 20, are:

- Atlantic coastal plain extending from Alabama northward through eastern Virginia and the Delmarva Peninsula
- Lower Mississippi River Basin, including especially cropland in northern Mississippi and Alabama
- cropland in southeastern Texas
- an area in northern Iowa including parts of southern Minnesota
- scattered areas within Michigan, Indiana, western Ohio, and central Wisconsin
- Southern Pennsylvania, New Jersey, and scattered area in New York and the New England states
- Willamette River Basin in Oregon

These vulnerable areas represent about 9 percent of the cropland acres included in the study. Areas of lowest vulnerability for nitrogen dissolved in leachate are colored green in map 20, and represent about 43 percent of the cropland acres included in the study. About 29 percent of the cropland acres had almost no dissolved nitrogen in leachate, shown by the grey areas in map 20.

As explained previously, model simulations did not explicitly account for tile drainage because of the lack of information on the presence or absence of tile drainage fields at NRI sample points. In heavily tiled cropland areas, however, it has been shown that much of the nitrate nitrogen dissolved in leachate that reaches the depth of the tile drainage field returns to surface water via the drainage tiles (Chung et al. 2001, 2002; Fausey et al. 1995; Fischer et al. 1999; Randall and Mulla 2001; Zucker and Brown 1998). Thus it is likely that the vulnerable acres shown in map 20 throughout most of the acreage in the Midwest are actually contributing to nitrogen in surface water runoff via dissolved nitrogen in leachate returning to surface water flows through tile drainage systems.

It is also likely that estimates of nitrogen dissolved in leachate are overstated in cropland areas where surface drainage systems are common because of the mitigating influence of denitrification processes, which were not taken into account in the model simulation. In the Southeast, for example, inherent hardpans and tillage pans can be a hindrance to nitrogen leaching and contribute to short-term waterlogging, resulting in substantial losses of nitrogen via denitrification.

Nitrogen dissolved in lateral subsurface flow.
Nitrogen loss through lateral subsurface flow was low in all model simulations, averaging less than 1 pound per acre overall and seldom exceeding 2 pounds per acre in specific model runs. Because of the low amounts lost through this pathway, the spatial distribution is not shown in a map. The ultimate fate of nitrogen loss from the field through lateral subsurface flow cannot be determined by EPIC. Subsurface flow occurs where there is a sloped landscape. After passing the edge of the field, it could return to the surface and contribute to surface water runoff, or it could continue to percolate into the soil as leachate. EPIC model estimates of lateral subsurface flow are not estimates of nitrogen loss through tile drains, although some subsurface lateral flow would be expected to return to surface water through drainage tiles in some situations.

Per-acre nitrogen loss by region

Southeast region. The highest per-acre losses occurred in the Southeast region, where the sum of losses from all loss pathways averaged 67 pounds per acre per year (table 36, fig. 17). Total nitrogen loss in this region represented 44 percent of the annual nitrogen inputs (commercial fertilizer applications, manure applications, bio-fixation, and atmospheric deposition), which was second highest among the seven regions. Most of the nitrogen loss was either nitrogen dissolved in leachate (44%) or nitrogen that volatilized (38%) (fig. 18). Nitrogen loss dissolved in leachate averaged 30 pounds per cropland acre per year—over twice as high as determined for any of the other regions. However, since cropland acres with high water tables are commonly found in areas throughout the Southeast region, a portion of the nitrogen attributed to nitrogen leaching in these model simulations is more likely to volatilize as gaseous nitrogen compounds as a result of de-

Figure 17 Average annual per-acre estimates of nitrogen loss–by region

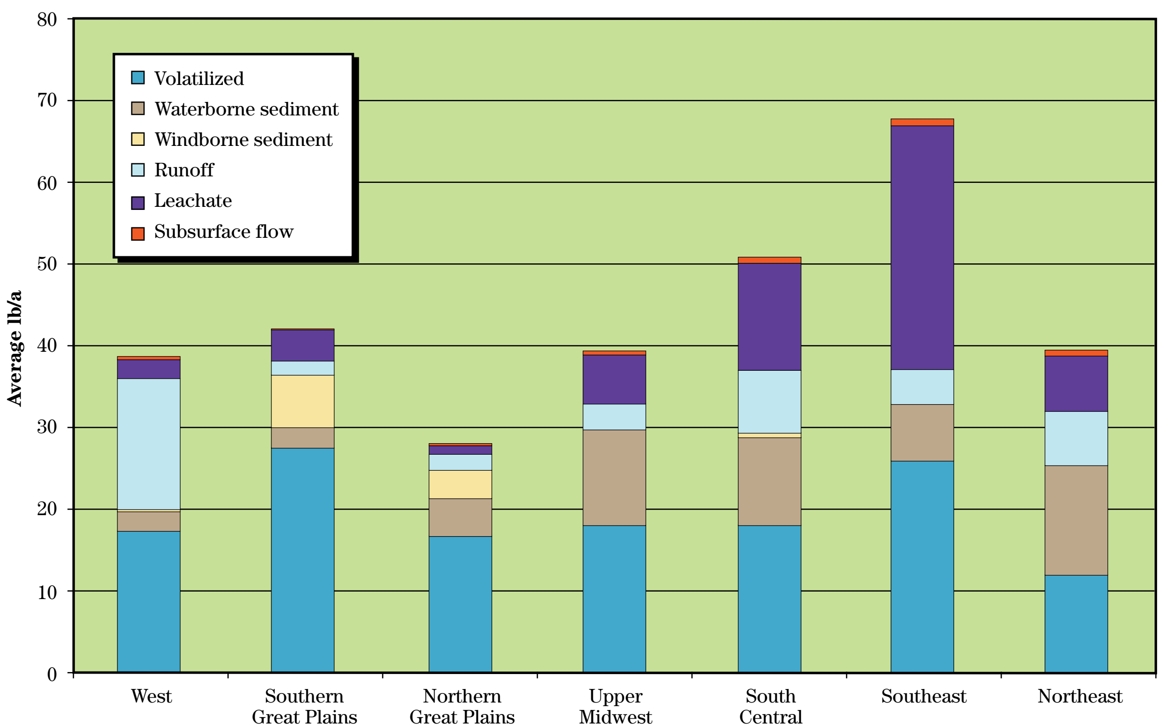
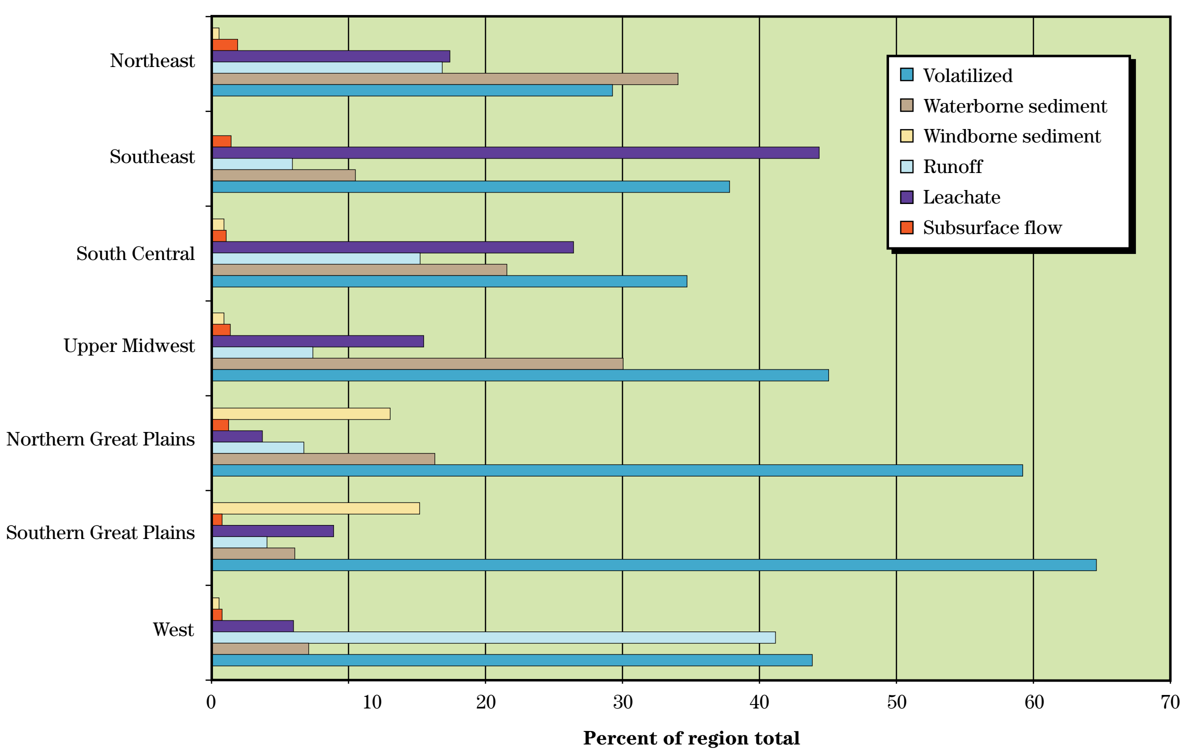


Figure 18 Nitrogen loss as a percentage of the total loss for each region



nitrification, or, in cases where ponding would have occurred, contributed to nitrogen losses in surface water runoff.

Corn acres in the Southeast region had among the highest nitrogen losses of any crop in any of the regions, averaging 115 pounds per acre per year for nitrogen loss summed over all pathways. For corn acres in this region, nitrogen loss dissolved in leachate averaged 51 pounds per acre per year and nitrogen volatilization loss averaged 46 pounds per acre. Nitrogen loss was also high for peanuts and soybeans, each averaging over 80 pounds per acre per year for nitrogen loss summed over all pathways. Nitrogen loss dissolved in leachate was 56 pounds per acre for peanuts in this region, which was the highest average loss for this pathway among all crops in all regions.

South Central region. The South Central region had the second highest per-acre nitrogen loss, averaging 51 pounds per cropland acre per year (table 36, fig. 17). All nitrogen pathways except windborne sediment and lateral subsurface flow had significant losses in the South Central region (fig. 18); the highest losses were due to volatilization and nitrogen dissolved in leachate. Total nitrogen loss in the South Central region represented 32 percent of annual nitrogen inputs.

Peanuts and rice had the highest nitrogen loss rates in this region, each averaging about 80 pounds per acre for nitrogen loss summed over all pathways. The dominant loss pathway for rice was nitrogen dissolved in surface water runoff; nitrogen loss for this pathway averaged 38 pounds per acre, the highest loss for nitrogen dissolved in surface water runoff among all crops and all regions. The dominant loss pathway for peanuts was nitrogen dissolved in leachate, with nitrogen loss for this pathway averaging about 50 pounds per acre per year. Per-acre nitrogen loss was also high for corn and soybean acres in this region, averaging over 60 pounds per acre for nitrogen loss summed over all pathways.

Southern Great Plains region. The Southern Great Plains region had the largest percentage of annual nitrogen inputs lost from farm fields—56 percent. The Southern Great Plains region had the lowest per-acre amount of nitrogen inputs, but had the third highest per-acre nitrogen loss. Model simulations showed that, on average, 42 pounds per acre of nitrogen was lost from cropland acres in this region each year. Nitrogen volatilization was the principal source of nitrogen loss in the region, accounting for 65 percent of all losses (fig. 18). High soil pH, high temperatures, and windy conditions are prevalent in this region, resulting in high rates of nitrogen volatilization. Nitrogen loss with windborne sediment was the second highest loss pathway, accounting for 15 percent of the nitrogen losses. Nitrogen loss with windborne sediment was higher in the Southern Great Plains than in any other region. Other loss pathways in this region were relatively small. Highest losses occurred for corn, sorghum, and peanuts within this region. Nitrogen lost to windborne sediment exceeded 12 pounds per acre, on average, for corn and cotton acres in this region.

Northeast region. Per-acre nitrogen losses in the Northeast region averaged 39 pounds per acre per year, of which waterborne sediment accounted for the largest percentage (34 percent) (figs. 17 and 18). Losses from volatilization accounted for 29 percent, and losses dissolved in runoff and leachate each accounted for 17 percent. The Northeast region had the lowest percentage loss of nitrogen inputs—16 percent—but also had the highest nitrogen inputs among the seven regions.

Corn silage had the highest nitrogen losses among crops in the Northeast, averaging 67 pounds per acre per year for the sum of losses from all pathways. Nitrogen lost with waterborne sediment averaged 41 pounds per acre for corn in this region, the highest per-acre loss for this pathway among all crops in all regions. Corn had the second highest nitrogen loss in the region, averaging 52 pounds per acre per year for the sum of losses over all pathways.

Upper Midwest region. Nitrogen loss in the Upper Midwest region averaged 39 pounds per cropland acre per year, slightly lower than in the Southern Great Plains and about the same as the Northeast and West regions. The dominant nitrogen loss pathways were volatilization (45%) and waterborne sediment (30%) (fig. 18). Highest losses occurred for corn and corn silage. Nitrogen loss in the Upper Midwest represented only 22 percent of the annual nitrogen inputs, which was second to the Northeast region in being the lowest percentage among all the regions.

West region. The West region averaged about 39 pounds per cropland acre of nitrogen losses from all pathways (table 36, fig. 17). These losses represented 28 percent of the annual nitrogen inputs in this region. Nitrogen loss dissolved in surface water runoff averaged 16 pounds per acre per year and nearly equaled the amount lost through volatilization. These two loss pathways accounted for the majority of nitrogen loss in the region. The percentage of nitrogen loss dissolved in surface water runoff was much higher in the West than in any other region—42 percent (fig. 18). These high losses of nitrogen dissolved in surface water runoff are associated with irrigation practices in the West.

Potatoes had the highest loss of nitrogen in the region, averaging 109 pounds per acre per year for the sum of all loss pathways. An average of 56 pounds per acre per year was due to nitrogen volatilization for potato acres, which is the highest loss for this pathway among all crops and within all regions. Corn silage had the second highest nitrogen loss at 72 pounds per acre for the sum of all loss pathways, followed by cotton at 55 pounds per acre.

Northern Great Plains region. The Northern Great Plains region had the lowest per-acre nitrogen loss at 28 pounds per acre per year for the sum of all loss pathways, consistent with the low level of nitrogen inputs for the region (table 36, fig. 17). Nitrogen losses represented about 34 percent of annual nitrogen inputs in this region. As observed for most regions, nitrogen volatilization accounted for most of the loss, but waterborne sediment and windborne sediment were also significant nitrogen loss pathways in the Northern Great Plains, accounting for 16 and 13 percent of nitrogen losses, respectively. Highest losses occurred for corn acres, which averaged 51 pounds per acre per year for the sum of losses from all pathways.

Per-acre nitrogen loss by crop

The per-acre estimates of nitrogen loss varied by crop, contributing to the diversity of nitrogen loss shown in maps 15 and 16 through 20 because of crop specific differences in nitrogen inputs and management practices.

The highest nitrogen loss on a per-acre basis was for potatoes (averaging 114 lb/a/yr), peanuts (averaging 74 lb/a/yr), and rice (averaging 69 lb/a/yr) (fig. 19). (These three crops also have the lowest cropland acres. As these crops were often minor crops in some regions, regional per-acre estimates of nitrogen loss were not always included in table 36.) For potatoes and peanuts, the dominant loss pathway was nitrogen dissolved in leachate. For rice, the dominant loss pathway was nitrogen dissolved in surface water runoff.

The lowest nitrogen losses were for grass hay and legume hay, averaging less than 20 pounds per acre for nitrogen loss from all pathways. These two crops usually had the lowest nitrogen loss estimates within each region, with regional average losses always less than 30 pounds per acre per year. Oats, spring wheat, and winter wheat also had low nitrogen losses, averaging between 23 and 30 pounds per acre for all acres and averaging less than 37 pounds per acre for all regions except the Southeast region. Nitrogen loss for winter wheat in the Southeast region was 69 pounds per acre per year, where nitrogen volatilization represented about half of the loss.

The overall average loss for the remaining crops—barley, corn, corn silage, cotton, sorghum, and soybeans—ranged from 38 to 56 pounds per acre per year (fig. 19).

Nitrogen loss estimates for irrigated crops often differed from nitrogen loss estimates for non-irrigated crops (table 37). For the sum of nitrogen losses for all pathways, about a third of the estimates were similar, about a third had substantially higher nitrogen losses for irrigated crops, and about a third had substantially lower nitrogen losses for irrigated crops. Examples of crops with substantially lower nitrogen loss estimates for irrigated acres are: sorghum and corn in the Southern Great Plains region, barley in the West region, cotton in the Southeast region, and corn in the Northern Great Plains region. Examples of crops with substantially higher nitrogen loss estimates for irrigated acres are peanuts and legume hay in the Southern Great Plains region and legume hay in the Northern Great Plains region. The largest differences were primarily a reflection of large differences in nitrogen volatilization. For some crops, nitrogen volatilization for non-irrigated crops exceeded nitrogen volatilization for irrigated crops by more than 30 pounds per acre. All irrigated acres had higher estimates of nitrogen dissolved in surface water runoff than non-irrigated acres in these model simulations. In most comparisons, nitrogen dissolved in leachate and nitrogen lost with waterborne sediment were generally similar; where large differences occurred, nitrogen loss from these two pathways was lower for irrigated acres than for non-irrigated acres.

Figure 19 Average annual per-acre estimates of nitrogen loss–by crop

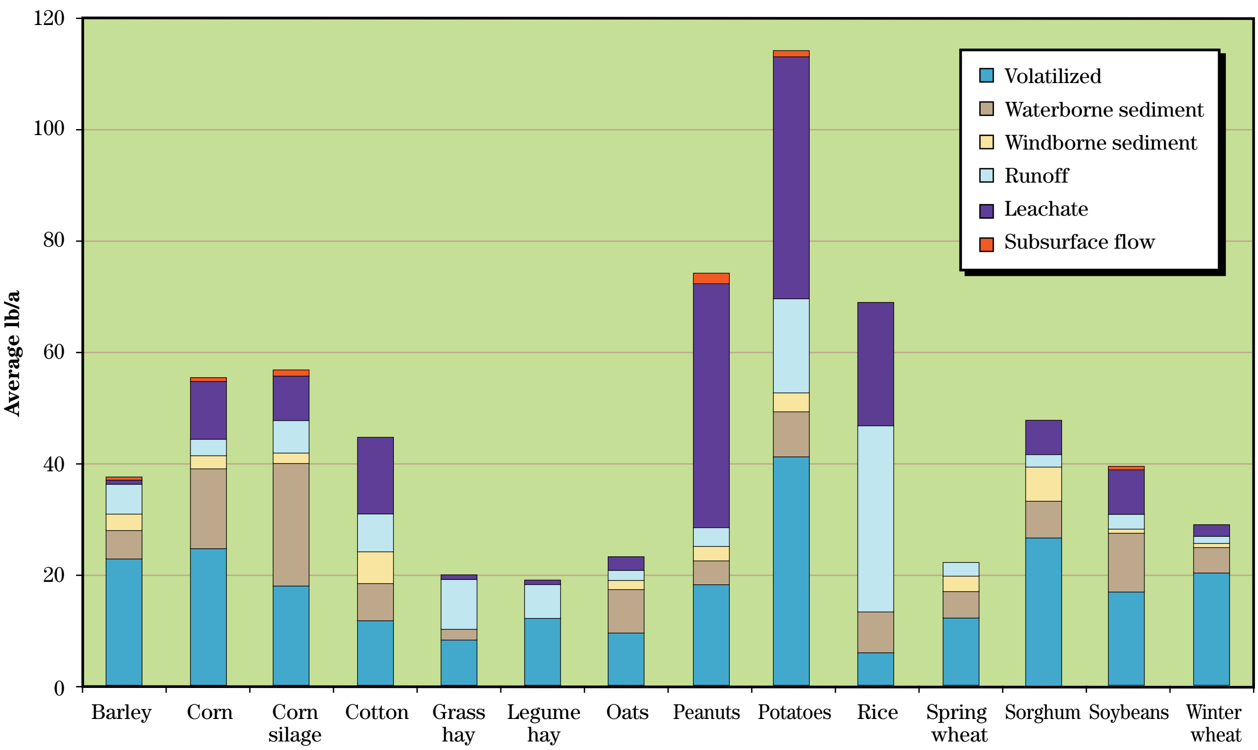


Table 37 Comparison of nitrogen loss estimates for irrigated crops to estimates for non-irrigated crops (average annual values)

		Acres (1,000s)		Sum of all loss pathways** (lb/a)		Volatilized (lb/a)		Dissolved in surface water runoff (lb/a)		Dissolved in leachate (lb/a)		Lost with waterborne sediment (lb/a)	
Region	Crop*	Irrigated	Non-irrigated	Irrigated	Non-irrigated	Irrigated	Non-irrigated	Irrigated	Non-irrigated	Irrigated	Non-irrigated	Irrigated	Non-irrigated
Northern Great Plains	Corn	6,680	8,785	41.7	57.9	18.2	35.9	3.9	1.8	3.9	3.3	7.0	8.7
	Legume hay	1,336	4,816	22.8	13.1	19.2	9.9	3.1	3.0	0.2	<0.1	0.2	0.1
	Soybeans	984	8,578	25.3	24.1	10.8	13.6	1.0	0.5	1.5	0.6	7.6	5.5
	Winter wheat	662	12,086	15.7	13.9	12.3	10.8	1.2	0.4	0.2	0.1	1.1	1.5
South Central	Corn	671	5,285	54.1	61.0	18.3	18.3	11.0	8.0	11.8	13.3	11.7	20.1
	Cotton	1,505	3,983	40.6	50.2	7.5	9.5	6.5	4.5	16.5	22.2	9.8	13.3
	Rice	3,004	0	77.9	NA	6.9	NA	37.8	NA	24.5	NA	8.6	NA
	Soybeans	3,585	10,498	63.3	63.9	26.0	24.7	10.5	6.8	14.3	18.5	12.1	12.5
	Winter wheat	554	7,341	29.1	32.6	16.9	18.9	3.0	1.8	2.7	2.9	6.3	8.6
Southeast	Cotton	307	2,115	30.0	47.9	6.6	11.3	3.5	1.9	13.6	28.5	5.4	5.6
Southern Great Plains	Corn	1,993	672	50.2	80.9	21.5	56.6	6.4	3.0	2.1	10.9	3.9	8.0
	Cotton	2,831	4,486	36.4	41.3	9.3	17.8	4.6	0.4	4.3	7.8	3.4	2.6
	Legume hay	414	263	23.9	12.1	17.8	11.7	5.8	0.3	0.2	<0.1	<0.1	<0.1
	Peanuts	325	159	60.6	42.8	20.1	11.7	6.8	1.4	19.6	20.9	2.4	2.2
	Sorghum	1,147	3,748	25.9	67.2	10.6	44.5	4.4	1.1	0.6	7.5	2.7	3.2
	Winter wheat	1,991	13,046	26.3	38.6	21.0	33.1	2.0	0.3	0.6	1.5	1.3	2.0
Upper Midwest	Corn	1,517	46,424	47.5	51.8	19.9	23.1	3.3	2.2	12.5	9.2	10.4	16.2
	Soybeans	641	39,409	31.6	32.5	13.0	14.7	1.6	1.4	7.9	4.7	8.5	11.1
West	Barley	601	357	24.3	53.5	3.6	33.6	19.8	3.0	0.1	1.8	0.3	12.4
	Corn silage	297	0	72.2	NA	30.4	NA	29.6	NA	8.8	NA	2.7	NA
	Cotton	1,631	0	55.3	NA	13.0	NA	38.9	NA	2.8	NA	0.4	NA
	Legume hay	1,688	159	20.9	12.3	18.2	8.8	2.4	2.2	0.2	0.1	<0.1	0.9
	Potatoes	329	0	108.9	NA	56.1	NA	38.7	NA	10.0	NA	0.6	NA
	Rice	599	0	23.5	NA	3.9	NA	11.9	NA	6.7	NA	1.0	NA
	Spring wheat	575	197	26.0	39.6	3.8	24.1	20.6	1.1	0.7	0.7	0.4	11.7
	Winter wheat	1,052	1,066	37.1	28.4	19.2	16.5	11.5	0.5	3.2	0.3	2.6	10.6

NA=not applicable
* Irrigated crops with more than 250,000 acres in a region are included in the table. These 26 crop-region combinations represent 92 percent of the irrigated acres included in the study.
** Includes nitrogen loss for all six pathways

Tons of nitrogen loss

Total nitrogen loadings are obtained when the acres of cropland are taken into account. Estimates of the annual tons of nitrogen loss for each of the five principal loss pathways are shown in maps 21–25. Each dot on these five maps represents 500 tons of nitrogen loss from cropland acres to facilitate spatial comparisons of nitrogen loadings.

The Upper Midwest region accounted for about 37 percent of total tons of nitrogen loss (table 35), nearly twice as much as any of the other six regions. The Upper Midwest Region also accounted for 37 percent of the cropland acres included in the study. The percentage of the total nitrogen lost each year was almost exactly the same as the percentage of total cropland acres in three other regions—the Northeast region, the Southern Great Plains region, and the West region (fig. 20). Notably, this occurred in the Upper Midwest and Northeast regions even though the percentages of nitrogen sources were disproportionately high in those regions. Nitrogen losses were disproportionately low in the Northern Great Plains, which is in part be due to the disproportionately low sources of nitrogen inputs (fig. 20). For the South Central and Southeast regions, however, nitrogen losses were disproportionately higher than the proportion of cropland acres.

Tons of nitrogen volatilization losses (map 21) tended to correspond to cropland acres, with some concentration in the Southern Great Plains region (table 35). Tons of nitrogen lost with windborne sediment were concentrated in the Southern Great Plains region (map 22). Over half of the nitrogen lost with waterborne sediment was in the Upper Midwest region (map 3, table 35), with disproportionately low losses in the two Great Plains regions. Nearly 60 percent of the nitrogen loadings for nitrogen dissolved in surface water runoff was in the South Central and Upper Midwest regions, with disproportionately high loadings relative to cropland acres in the West region (map 24, table 35). The Upper Midwest and the South Central regions accounted for the bulk (65%) of nitrogen loadings from nitrogen dissolved in leachate (map 25, table 35), with disproportionately high loadings occurring in the Southeast region.

Corn accounted for the largest share of total nitrogen loss (table 35). Corn acres comprise 26 percent of the cropland acres included in the study. However, corn accounted for 36 percent of the total nitrogen losses, due in part to corn accounting for 50 percent of all commercial fertilizer and manure nitrogen applied (table 38).

Soybeans accounted for the second largest share of nitrogen loss (table 35). In contrast to corn, however, nitrogen loss for soybeans was almost exactly the same proportion as acres of soybeans—23 percent (table 38). Since only 2 percent of the commercial fertilizer and manure nitrogen was applied to soybeans, it is clear that nitrogen from bio-fixation was the primary source of nitrogen loss on soybean acres, and that these losses were directly proportional to the acres of soybeans. Peanuts, the other legume row crop, similarly had disproportionately low commercial fertilizer and manure nitrogen sources relative to acres, but had disproportionately high losses of nitrogen (proportion for nitrogen loss was twice that of acres), probably because of inherent soil and climate characteristics in peanut growing regions. Legume hay, on the other hand, was associated with 24 percent of all nitrogen sources but only accounted for 3.9 percent of nitrogen losses, while accounting for over twice that many acres (legume hay accounted for 8.3 percent of total cropland acres).

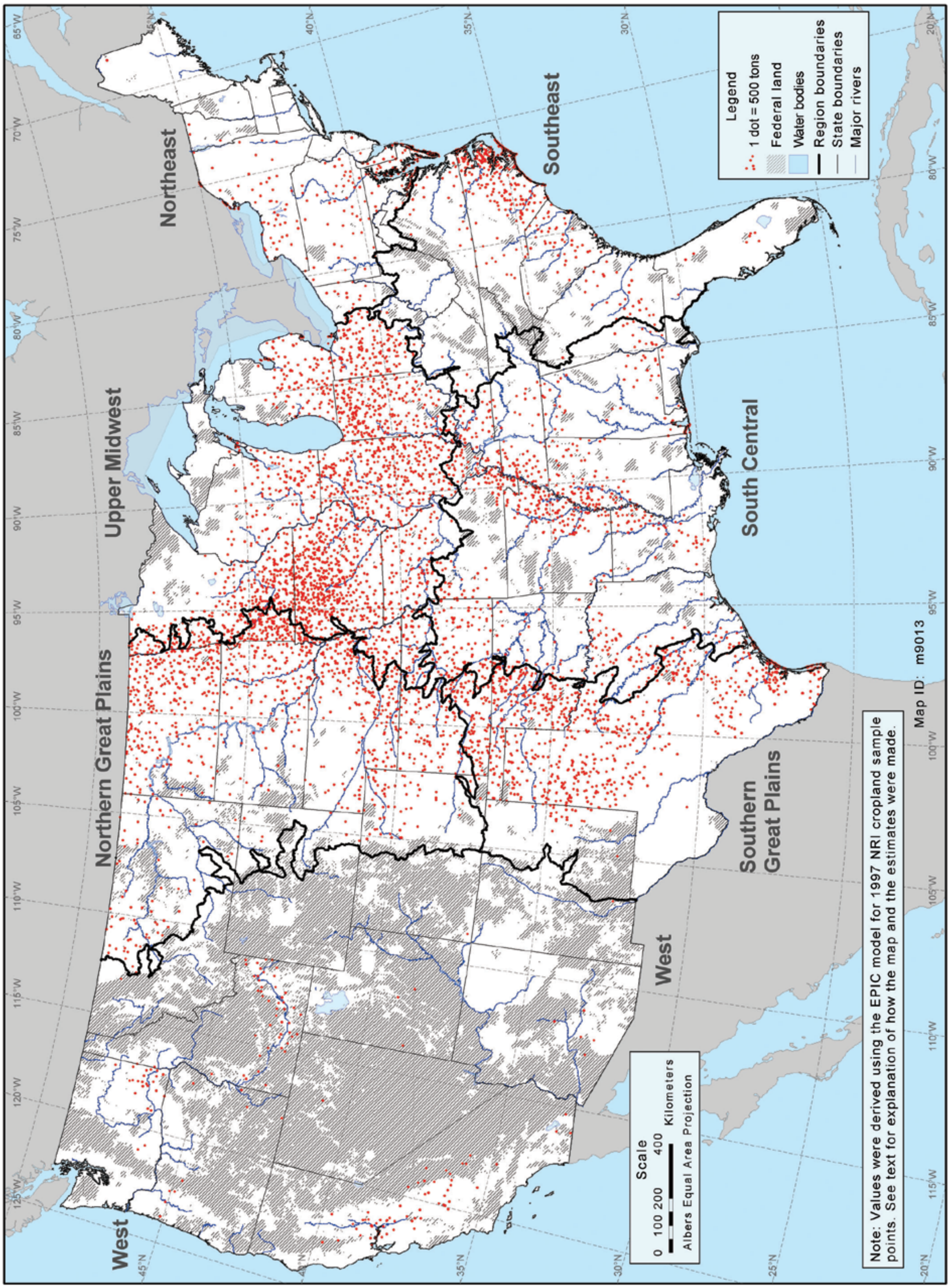
In addition to corn and peanuts, potatoes and rice also had disproportionately high losses of nitrogen, where the proportion of nitrogen loss was nearly twice or more the proportion of acres. Grass hay, spring wheat, oats, and winter wheat had disproportionately low losses of nitrogen relative to acres, in addition to legume hay. For the remaining crops, the shares of total nitrogen loss and acres were closer.

Effects of soil properties on nitrogen loss

Soil properties such as texture and hydrologic soil group explain some of the variability in nitrogen loss results (tables 39 and 40), and also provide opportunities for identifying the most susceptible cropland acres at the local level.

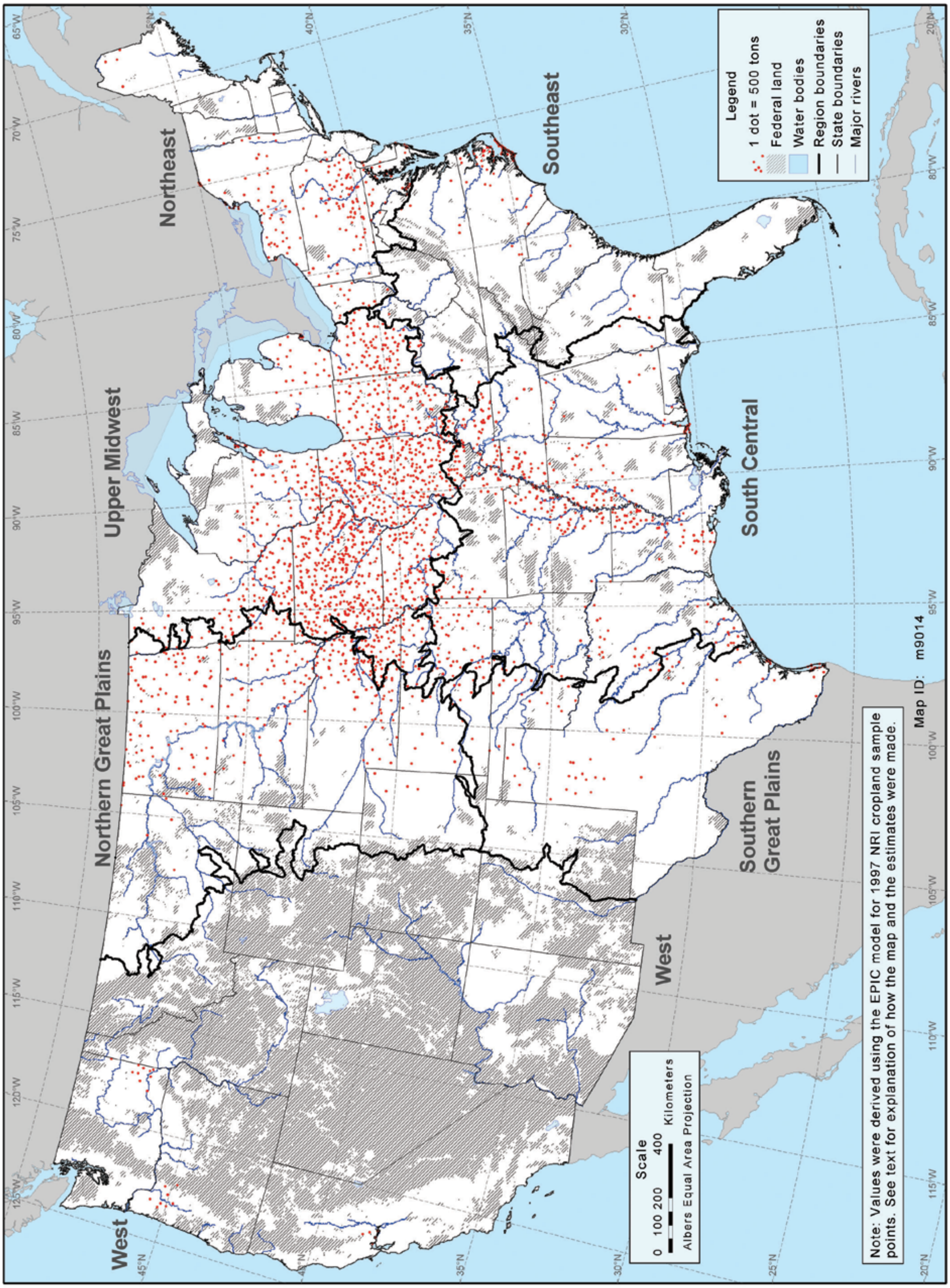
Model simulation results showed that extremely high nitrogen loss occurred on organic soils, averaging over 300 pounds per acre per year (table 39); these soils comprise less than half of one percent of the cropland acres included in the study. The very high levels of organic material in these soils rapidly mineralize when the soil is tilled, releasing significant amounts of nitrogen compounds, a portion of which are subsequently lost to the atmosphere or lost from the field with wind

Map 21 Estimated average annual tons of nitrogen lost to the atmosphere



Map 22 Estimated average annual tons of nitrogen lost with windborne sediment

Map 23 Estimated average annual tons of nitrogen lost with waterborne sediment



Map 24 Estimated average annual tons of nitrogen dissolved in surface water runoff

Map 25 Estimated average annual tons of nitrogen dissolved in leachate

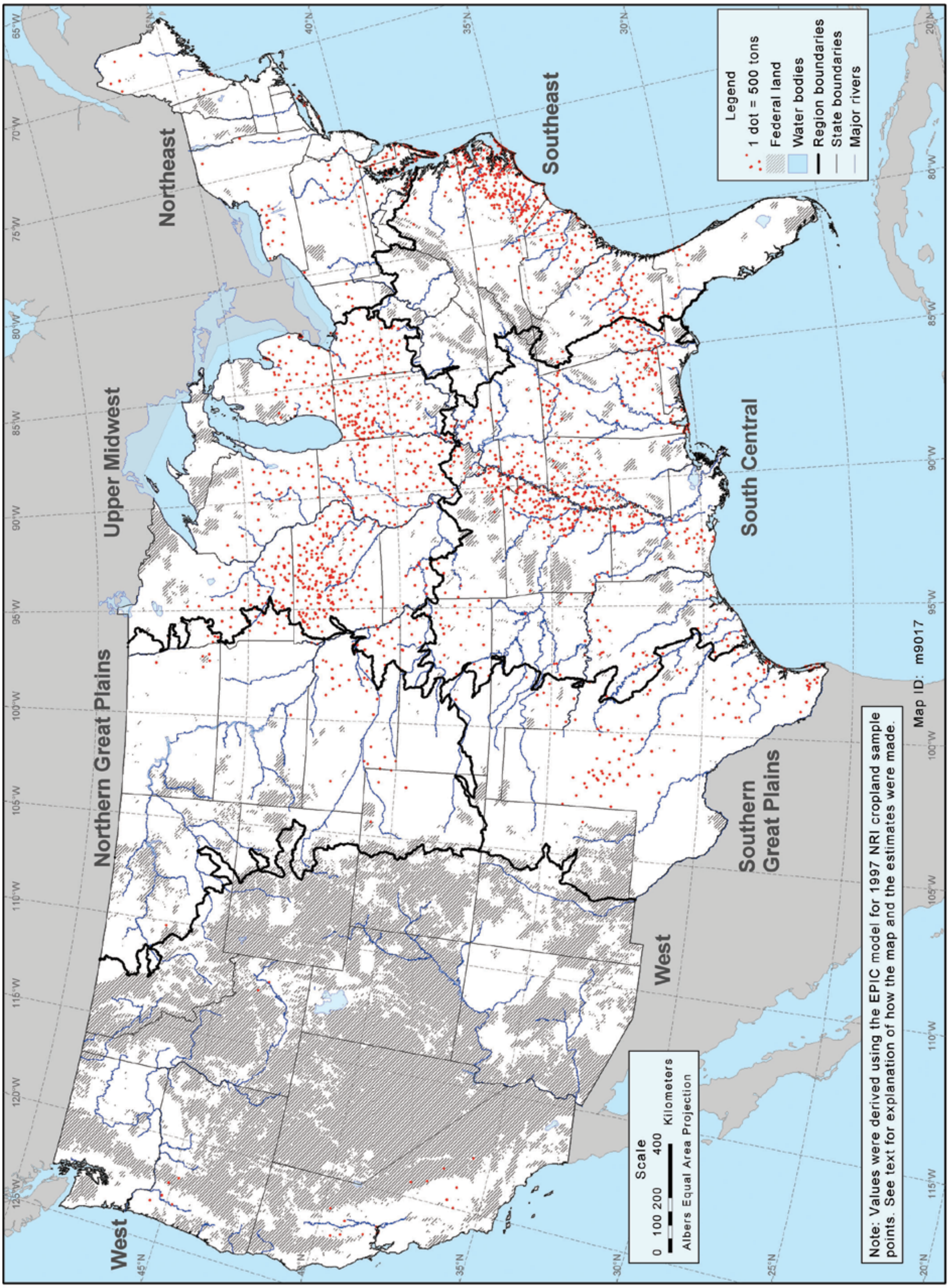


Figure 20 Regional percentages of the total for cropland areas, all nitrogen sources, commercial fertilizer and manure nitrogen, and total nitrogen loss

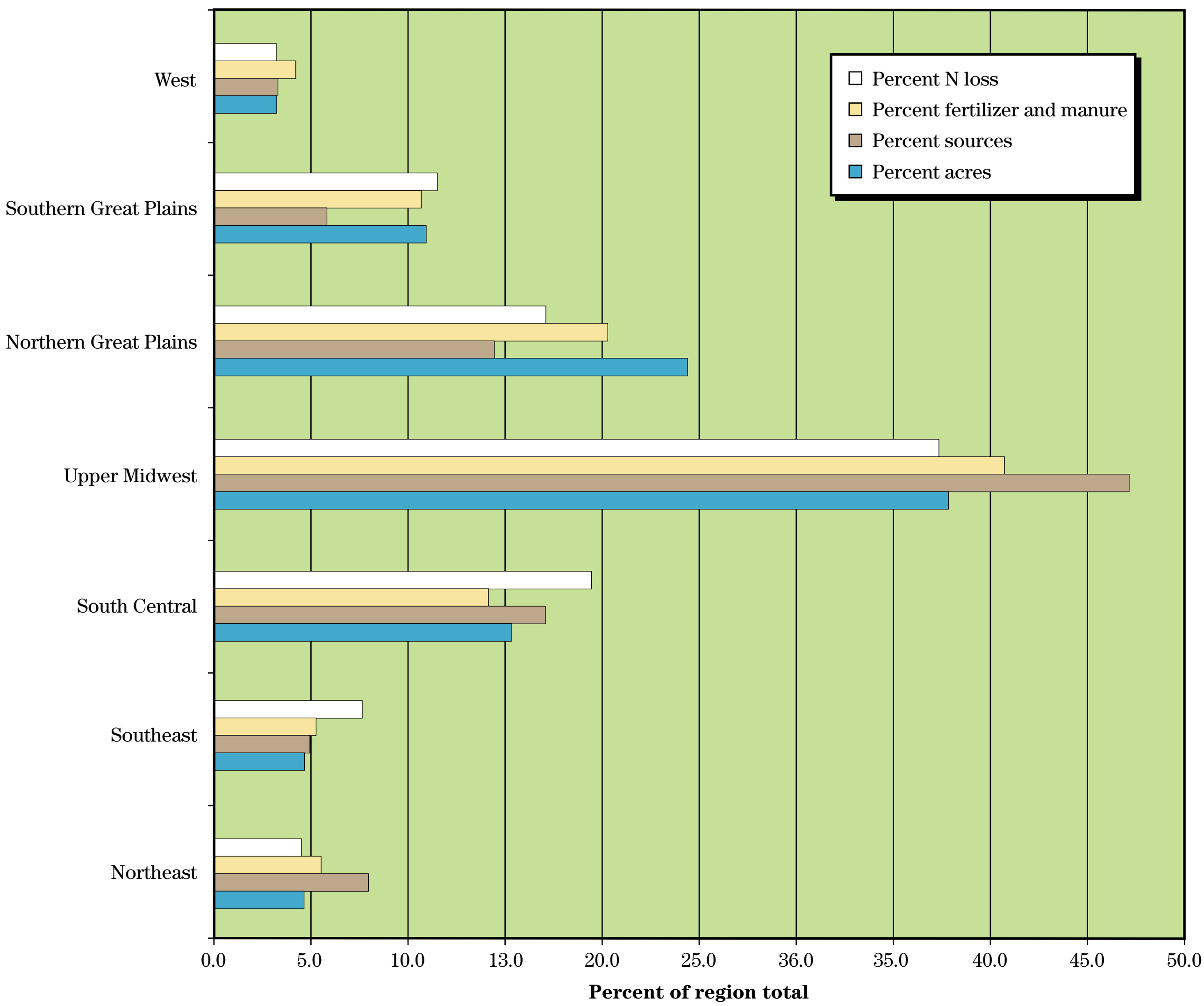


Table 38 Percentages by crop of the total for cropland acres, total nitrogen loss, all nitrogen sources, and commercial fertilizer and manure nitrogen source

Crop	Percent of total cropland acres	Percent of total nitrogen losses	Percent of all nitrogen sources	Percent of commercial fertilizer and manure nitrogen applied
Disproportionately high nitrogen loss relative to acres				
Corn	26.2	36.3	24.5	50.3
Peanuts	0.6	1.2	0.4	0.2
Potatoes	0.3	0.9	0.4	0.8
Rice	1.2	2.1	1.0	1.9
Disproportionately low nitrogen loss relative to acres				
Legume hay	8.3	3.9	24.0	4.7
Grass hay	4.9	2.4	2.8	5.5
S wheat	6.9	3.9	2.2	4.4
W wheat	15.1	11.1	6.2	12.3
Oats	1.3	0.7	0.3	0.5
Nitrogen loss approximately proportional to acres				
Soybeans	22.6	22.8	29.7	2.1
Barley	1.6	1.5	0.9	1.8
Corn silage	1.7	2.5	2.4	5.0
Cotton	5.6	6.3	3.0	5.9
Sorghum	3.7	4.4	2.3	4.7
All crops	100.0	100.0	100.0	100.0

Table 39 Sources of nitrogen applied and estimates of nitrogen loss–by soil texture class (average annual values)

Soil texture class	Percent of cropland acres	Nitrogen applied: Commercial fertilizer (lb/a)	Nitrogen applied: Manure (lb/a)	Nitrogen loss pathways: Lost with waterborne sediment (lb/a)	Lost with windborne sediment (lb/a)	Volatilized (lb/a)	Dissolved in surface water runoff (lb/a)	Dissolved in leachate (lb/a)	Dissolved in lateral subsurface flow (lb/a)	Sum of all losses (lb/a)
Coarse	5.1	66.0	10.9	1.6	5.7	17.8	2.3	22.7	0.8	50.8
Moderately coarse	10.9	60.1	8.9	3.8	2.5	16.9	3.8	12.4	0.6	40.1
Medium	51.4	58.2	7.6	9.6	1.3	16.2	4.2	4.8	0.4	36.4
Moderately fine	26.2	57.5	6.0	8.9	1.8	19.7	2.8	4.3	0.3	37.9
Fine	6.0	51.1	3.3	10.0	1.2	23.7	6.3	6.9	0.3	48.5
Organic	0.4	71.6	12.7	39.1	0.6	213.8	5.6	49.2	0.3	308.6
Other	<0.1	55.8	13.9	0.7	0.2	14.9	2.6	16.4	0.9	35.7
All	100.0	58.3	7.3	8.5	1.8	18.5	3.8	6.7	0.4	39.7

Table 40 Sources of nitrogen applied and estimates of nitrogen loss–by hydrologic soil group (average annual values)*

Hydrologic soil group	Percent of cropland acres	Nitrogen applied: Commercial fertilizer (lb/a)	Nitrogen applied: Manure (lb/a)	Nitrogen loss pathways: Lost with waterborne sediment (lb/a)	Lost with windborne sediment (lb/a)	Volatilized (lb/a)	Dissolved in surface water runoff (lb/a)	Dissolved in leachate (lb/a)	Dissolved in lateral subsurface flow (lb/a)	Sum of all losses (lb/a)
A	3.5	65.4	10.4	1.1	6.5	17.4	2.0	22.9	0.8	50.5
B	55.7	58.9	7.8	7.6	2.0	17.6	2.4	6.0	0.5	36.1
C	25.7	57.1	7.4	10.4	0.9	16.3	4.8	5.7	0.4	38.5
D	15.1	55.7	4.0	9.7	1.5	20.5	7.7	6.2	0.2	45.9
All	100.0	58.2	7.2	8.4	1.8	17.7	3.8	6.5	0.4	38.7

* Excludes organic soils

and water erosion. Average application rates for commercial fertilizer and manure were higher on these soils than other soil texture groups (table 39), but not enough to explain the extremely high nitrogen loss rates. Most of the nitrogen loss from organic soils is through volatilization (69%), but high amounts are also lost through leaching and with waterborne sediment. About half of the organic soils are classified as hydrologic soil group A, which has a lower runoff potential and higher infiltration rate than other soil hydrologic groups. Group A soils are found predominately in the Southeast and Upper Midwest regions.

Apart from the high loss rates for organic soils, soil texture and hydrologic soil group had little influence on nitrogen volatilization (tables 39 and 40). Losses were slightly higher for hydrologic soil group D soils when organic soils are excluded.

Nitrogen lost with windborne sediment was strongly influenced by soil texture and hydrologic soil group (tables 39 and 40). Soil texture and hydrologic soil group effects were similar to effects on wind erosion rates shown in figure 12. Highest losses occurred for coarse textured soils and for soils in hydrologic soil group A.

Soil texture and hydrologic soil group also had a pronounced effect on estimates of nitrogen lost with waterborne sediment (tables 39 and 40, fig. 21). Low levels of nitrogen loss occurred on hydrologic soil group A soils, as well as coarse and moderately coarse textured soils. Except for organic soils, the relationship between nitrogen lost with waterborne sediment and soil properties was generally similar to that observed for sediment loss in figure 11.

Loss of nitrogen dissolved in surface water runoff was influenced more by hydrologic soil group than soil texture (fig. 22). Highest losses were for hydrologic soil group D soils, where the average annual loss was about 8 pounds per acre. Hydrologic soil group D soils are the dominant soil type in the South Central region, representing over 40 percent of the cropland acres in that region. Hydrologic soil group A had the lowest loss of nitrogen dissolved in surface water runoff, averaging only 2 pounds per acre per year.

Soil texture played the major role in determining nitrogen dissolved in leachate (fig. 23). Average nitrogen leaching rates were highest for organic soils, followed by coarse textured soils (23 lb/a/yr) and moderately coarse textured soils (12 lb/a/yr). Medium textured soils in hydrologic soil group A also had significant loss, averaging 16 pounds per acre per year. Finer textured soils had average nitrogen leaching losses below 7 pounds per acre per year. This relationship between nitrogen leaching and soil texture reflects the tendency for coarser soil to have larger, more continuous pathways or pores for downward movement of water.

Soil types with the highest nitrogen losses occur less frequently on the landscape than soil types with the lowest nitrogen losses. Organic soils, which had extremely high nitrogen losses in these model simulations, represented less than 0.5 percent of cropland acres. Apart from the organic soils, coarse textured soils had the highest total nitrogen loss (51 lb/a/yr), as did hydrologic group A soils (50 lb/a/yr excluding organic soils). However, these soil groups together comprise only a small fraction of the total cropland acres (<6%). Overall, medium textured soils had the lowest total nitrogen loss rates, averaging 36 pounds per acre per year, and among the hydrologic soil groups, hydrologic soil group B had the lowest total nitrogen loss rates, also averaging 36 pounds per acre per year (tables 39 and 40). Hydrologic soil group B with medium soil texture is the dominant soil type for cropland acres included in the study, representing about 30 percent of cropland acres (table 5).

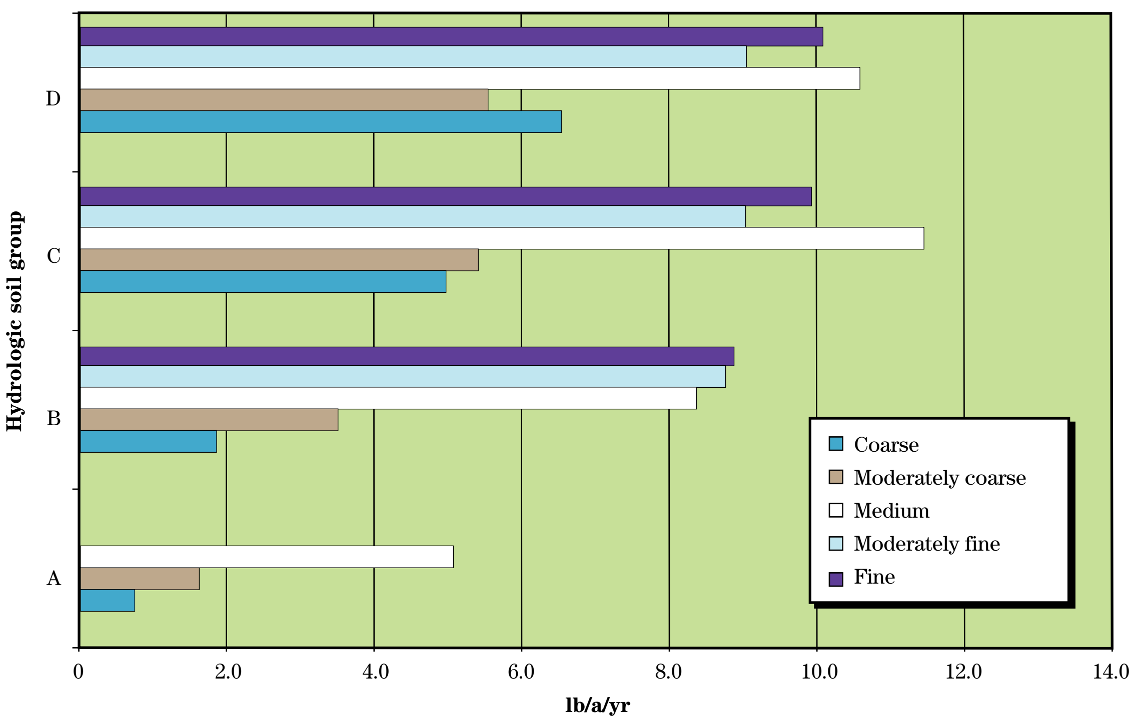
Example of spatial variability of nitrogen loss

Two specific examples of how nitrogen loss varies within a local area are shown in figure 24. The diversity of soil types represented in the model simulations for these two Iowa watersheds was discussed in a previous section (fig. 4). Dominant soils from figure 4 are shown in red in figure 24. Overall, commercial fertilizer and manure nitrogen inputs were about the same in both of these watersheds.

Total nitrogen loss was slightly lower for the Lower Iowa watershed (44.5 lb/a/yr) than for the Floyd watershed (53.1 lb/a/yr). The predominant loss pathway differed between the two watersheds as well; in the Floyd, about half of the nitrogen loss was through volatilization, whereas about half of the losses in the Upper Iowa watershed were with waterborne sediment.

Variability in total nitrogen loss by soil cluster was quite high in both watersheds, ranging from 14 to 113

Figure 21 Average annual loss of nitrogen with waterborne sediment–by hydrologic soil group and soil texture class



Note: Results for organic soils are not shown (see table 26).

Figure 22 Average annual loss of nitrogen dissolved in surface water runoff–by hydrologic soil group and soil texture class

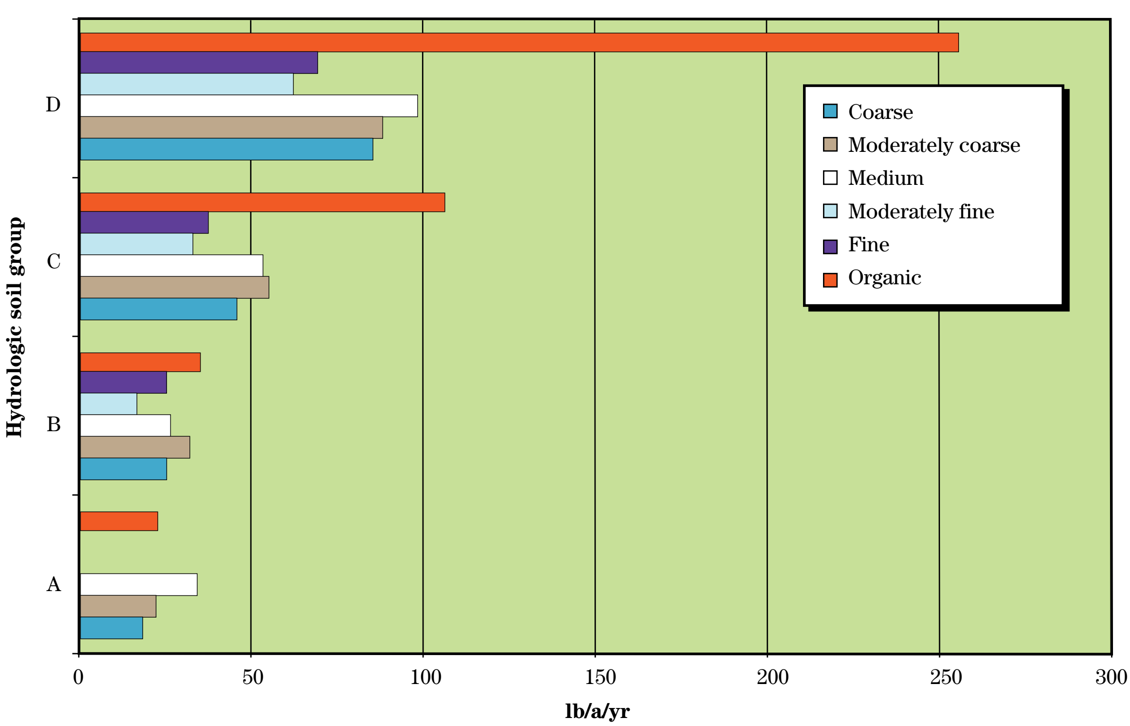


Figure 23 Average annual loss of nitrogen dissolved in leachate–by hydrologic soil group and soil texture class

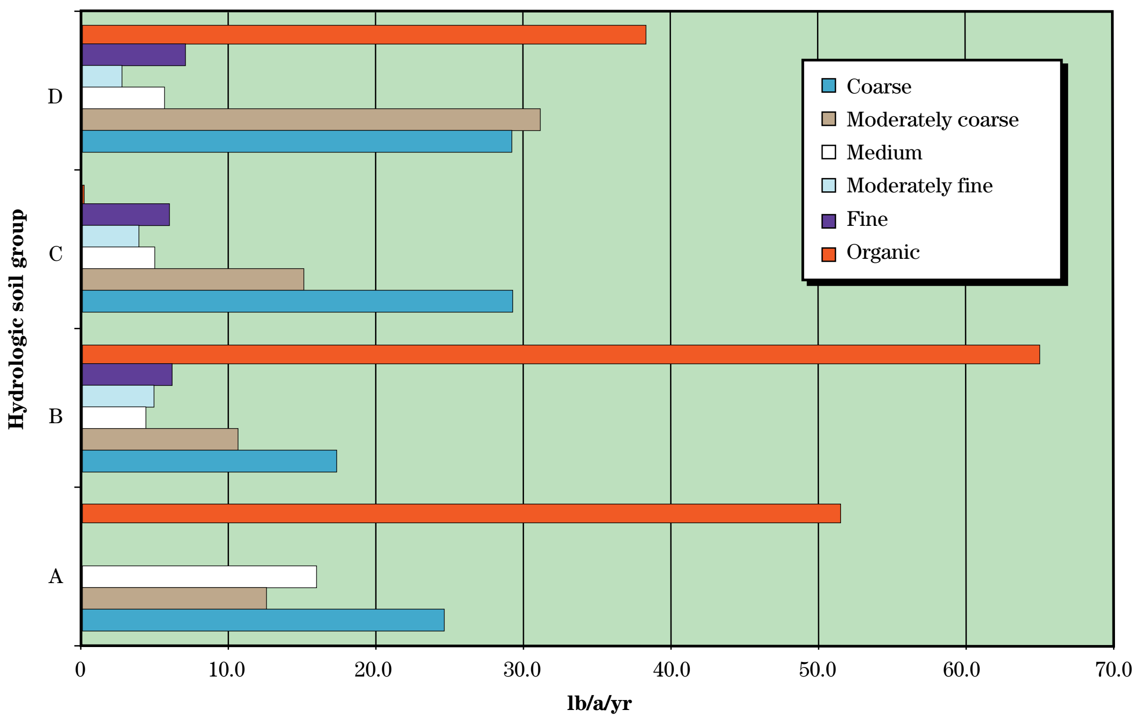
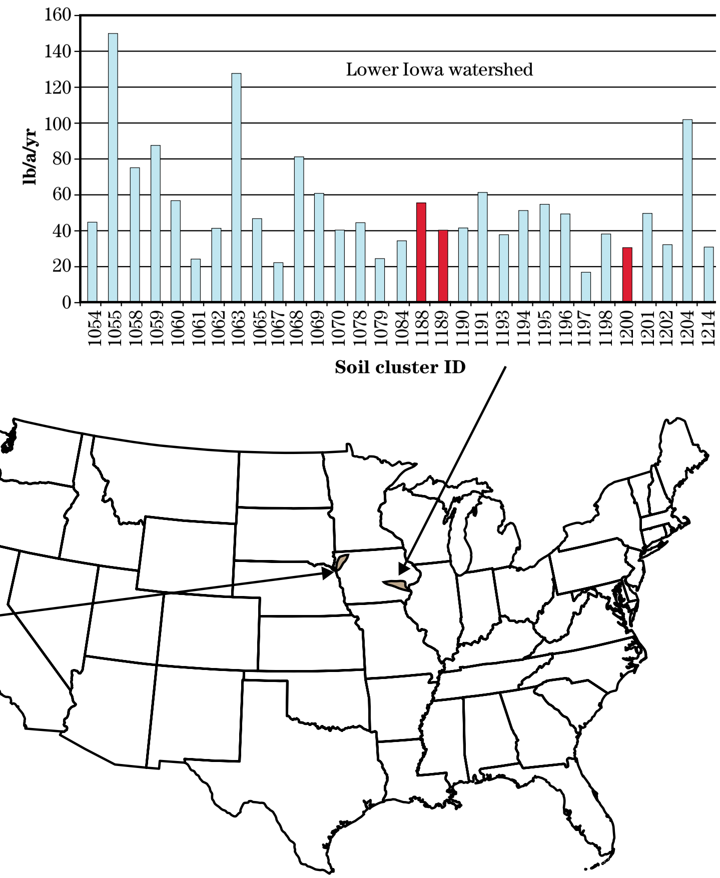
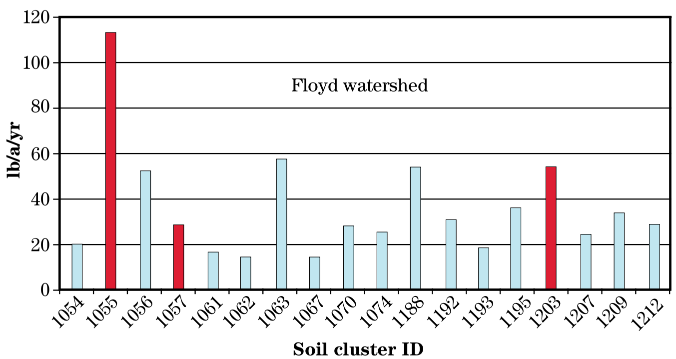


Figure 24 Variability in nitrogen loss estimates (sum of all loss pathways) within two IA watersheds

Soil cluster	Representative soil	Texture group	Hydrologic soil group	Soil cluster	Representative soil	Texture group	Hydrologic soil group
1054	Fairhaven	Medium	B	1189	Lagoda	Medium	B
1055	Kossuth	Moderately fine	B	1190	Sharpsburg	Moderately fine	B
1056	Alton	Moderately fine	C	1191	Adair	Medium	C
1057	Galva	Moderately fine	B	1192	Kenyon	Medium	B
1058	Hoopeston	Moderately coarse	B	1193	Marshall	Moderately fine	B
1059	Coland	Moderately fine	B	1194	Sparta	Coarse	A
1060	Tama	Medium	B	1195	Huntsville	Medium	B
1061	Coppock	Medium	B	1196	Downs	Medium	B
1062	Shelby	Moderately fine	B	1197	Village	Medium	B
1063	Turlin	Medium	B	1198	Lineville	Medium	C
1065	Fayette	Medium	B	1200	Humeston	Medium	C
1067	Nodaway	Medium	B	1201	Lamoni	Fine	C
1068	Gara	Medium	C	1202	Wabash	Moderately fine	D
1069	Lindley	Medium	C	1203	Terril	Medium	B
1070	Colo	Moderately fine	B	1204	Floyd	Medium	B
1074	Ida	Medium	B	1207	Monona	Medium	B
1078	Adair	Moderately fine	C	1209	Racine	Medium	B
1079	Lamont	Moderately coarse	B	1212	Spicer	Moderately fine	B
1084	Dickinson	Moderately coarse	B	1214	Chelsea	Coarse	A
1188	Ely	Medium	B				





pounds per acre in the Floyd watershed and 18 to 150 pounds per acre in the Upper Iowa watershed. In both watersheds, the highest loss occurred for soil cluster 1055 (Kossuth soil), and the second highest loss occurred for soil cluster 1063 (Turlin soil). In the Floyd watershed, about 74 percent of the total nitrogen loss was associated with the 5 soil clusters with the highest loss rates, representing 50 percent of the acres. In the Lower Iowa watershed, the highest losses occurred on soils with few acres—the 8 soil clusters with the highest losses accounted for 16 percent of the total nitrogen loss, but represented only 9 percent of the cropland acres.

Effects of tillage practices on nitrogen loss

Tillage practices were shown to have a significant influence on sediment loss and wind erosion estimates (tables 24 and 30). Model simulations showed that the effect of tillage practices on nitrogen loss estimates was also significant, but not as pronounced as observed for sediment loss. As discussed earlier in this report (table 12 and related discussion), the subset of model runs where all three tillage systems—conventional tillage, mulch tillage, and no-till—were present within a URU was used as the domain for examining the effects of tillage. This tillage comparison subset of model runs included eight crops and represented about 70 percent of the cropland acres covered by the study.

For the 208 million acres in the tillage comparison subset, the tillage-effects baseline nitrogen loss (sum of all loss pathways) averaged 41 pounds per acre per year (table 41), which is nearly the same as the estimate for the full set of NRI sample points included in the study. Model simulation results showed that nitrogen loss summed over all loss pathways would have averaged 44 pounds per acre per year if conventional tillage had been used on all acres, indicating that the tillage practices currently in use have reduced nitrogen loss (sum of all pathways) by 7 percent. As shown for sediment loss, nitrogen loss estimates for mulch tillage were similar to the tillage-effects baseline. Nitrogen loss estimates assuming mulch tillage was used on all acres averaged about 10 percent less than if conventional tillage had been used on all acres. Simulation of full implementation of no-till resulted in an average nitrogen loss of 32 pounds per acre per year, a decrease of nearly 9 pounds per acre, on average, when compared to the tillage-effects baseline. Full implementation of no-till would have the greatest effect in three regions—the Northeast, the Upper Midwest, and the Southern Great Plains regions. The Southeast region, which had the largest estimate of nitrogen loss among the seven regions, would benefit the least in terms of reduced nitrogen loss from additional mulch tillage and only modestly with additional no-till.

The effect of tillage on nitrogen loss estimates varied by crop (table 41). The largest reductions in nitrogen loss for full implementation of mulch tillage compared to the baseline were for barley and spring wheat. Nitrogen loss reductions of about 10 pounds per acre or more, on average, would be obtained for these two crops, as well as three additional crops—corn, corn silage, and sorghum—with full implementation of no-till.

Most of the differences in nitrogen loss among the three tillage systems are for losses that are due to windborne sediment, waterborne sediment, and nitrogen volatilization (fig. 25). In these model simulations, tillage had little effect on soluble nitrogen lost with either surface water runoff or leachate.

Effects of three conservation practices on nitrogen loss

In addition to tillage effects, three conservation practices—contour farming, stripcropping, and terraces—were shown to have a significant influence on nitrogen loss estimates on the basis of the model simulations. As shown for tillage practices, the effect of these three conservation practices on nitrogen loss estimates was modest compared to their effect on sediment loss. For comparison to the results for the model runs that included conservation practices, an additional set of model runs were conducted after adjusting model settings to represent no practices. The difference between the no-practices scenario and the conservation-practices baseline scenario (consisting of the original model runs for NRI sample points with conservation practices) is used here to assess the extent to which conservation practices reduced the nitrogen loss estimates (see table 13 and related discussion).

For the 31.7 million acres modeled with conservation practices, nitrogen loss estimates (sum of all loss pathways) averaged 34 pounds per acre per year (table 42), which was lower than the 40 pounds per acre estimate for the full set of NRI sample points included in the study. Had conservation practices not been accounted for in the model simulations, nitrogen loss estimates on these acres would have averaged 41 pounds

Table 41 Effects of tillage practices on estimates of nitrogen loss, sum of all loss pathways (lb/a/yr)

		Nitrogen loss, all pathways				Change relative to the tillage-effects baseline			Change relative to conventional tillage	
	Acres in tillage comparison subset (1,000s)	Tillage-effects baseline	Conventional tillage	Mulch tillage	No-till	Conventional tillage	Mulch tillage	No-till	Mulch tillage	No-till
By region										
Northeast	6,034	50.4	54.7	49.0	38.3	4.3	-1.4	-12.1	-5.7	-16.4
Northern Great Plains	56,551	82.8	86.6	83.7	77.2	3.8	0.9	-5.6	-2.9	-9.4
South Central	24,879	51.4	54.5	52.5	44.1	3.1	1.1	-7.3	-2.0	-10.4
Southeast	4,442	41.9	45.2	42.2	34.2	3.3	0.3	-7.6	-3.0	-11.0
Southern Great Plains	17,746	28.9	31.9	25.1	19.2	3.0	-3.8	-9.7	-6.8	-12.7
Upper Midwest	96,330	42.6	44.9	38.0	31.9	2.3	-4.6	-10.7	-6.9	-13.0
West	1,661	35.2	39.1	30.7	26.0	4.0	-4.5	-9.1	-8.5	-13.1
By crop										
Barley	3,256	39.5	42.6	28.2	24.0	3.1	-11.3	-15.6	-14.4	-18.7
Corn	71,016	53.7	57.4	53.9	42.2	3.7	0.1	-11.6	-3.5	-15.2
Corn Silage	4,082	55.6	58.2	54.7	42.5	2.6	-0.9	-13.1	-3.5	-15.6
Oats	2,078	21.9	23.9	18.0	15.7	2.0	-3.9	-6.2	-6.0	-8.2
Spring wheat	18,074	21.1	23.7	13.9	11.3	2.6	-7.2	-9.8	-9.9	-12.4
Sorghum	7,697	47.7	50.7	47.3	36.0	2.9	-0.4	-11.8	-3.3	-14.7
Soybeans	62,967	38.1	41.6	39.0	33.0	3.5	0.9	-5.1	-2.6	-8.6
Winter wheat	38,473	27.7	29.8	24.2	21.5	2.1	-3.5	-6.2	-5.6	-8.3
All crops and regions	207,642	40.6	43.8	39.4	32.1	3.2	-1.2	-8.5	-4.4	-11.7

Note: The subset used for this analysis includes only those URUs where all three tillage systems were present. The tillage-effects baseline results represent the mix of tillage systems as reported in the Crop Residue Management Survey for 2000 (CTIC 2001). Tillage-effects baseline results reported in this table will differ from results reported in table 36 because they represent only about 70 percent of the acres in the full database. Results presented for each tillage system represent nitrogen loss estimates as if all acres had been modeled using a single tillage system.

Figure 25 Effects of tillage practices on nitrogen loss estimates–by loss pathway

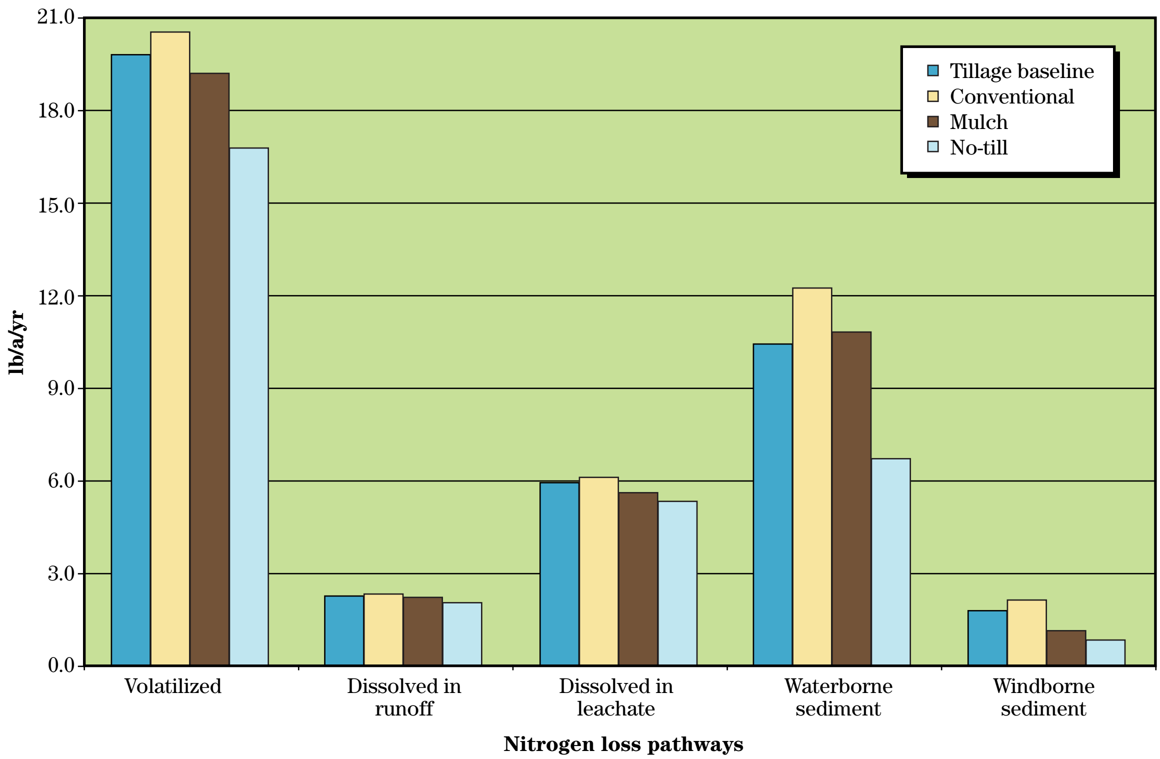


Table 42 Effects of three conservation practices on estimates of nitrogen loss, sum of all loss pathways (lb/a/yr)

				Nitrogen loss			
Region	Conservation practices	Number of NRI sample points	Acres (1,000s)	Conservation-practices baseline scenario	No-practices scenario	Difference	Percent difference relative to no-practices scenario
All regions	Contour farming only	3,728	5,965	40.5	50.2	-9.7	-19
	Contour farming and stripcropping	1,183	1,764	28.7	40.3	-11.6	-29
	Contour farming and terraces	7,883	14,728	33.0	40.4	-7.4	-18
	Contour farming, stripcropping, and terraces	31	64	31.0	38.9	-7.9	-20
	Stripcropping only	1,308	2,930	21.0	23.5	-2.5	-11
	Terraces only	3,268	6,285	38.1	40.3	-2.2	-5
	All practices	17,401	31,737	34.1	40.6	-6.6	-16
Northeast	Contour farming only	338	485	46.2	54.7	-8.5	-15
	Contour farming and stripcropping	454	595	36.7	49.7	-13.0	-26
	Stripcropping only	423	526	39.4	49.3	-9.9	-20
	All practices	1,215	1,606	40.4	51.1	-10.6	-21
Southeast	Contour farming only	275	456	51.3	56.2	-4.8	-9
	Contour farming and terraces	132	234	44.9	48.1	-3.1	-7
	Terraces only	52	92	43.0	45.0	-2.0	-5
	All practices	459	782	48.4	52.4	-4.0	-8
South Central	Contour farming only	110	172	58.4	64.5	-6.1	-9
	Contour farming and terraces	1,173	1,963	37.1	43.8	-6.7	-15
	Terraces only	1,169	1,974	36.8	39.2	-2.4	-6
	All practices	2,452	4,109	37.8	42.5	-4.6	-11
Upper Midwest	Contour farming only	2,625	4,239	37.5	49.0	-11.5	-23
	Contour farming and stripcropping	702	1,106	23.9	35.1	-11.3	-32
	Contour farming and terraces	3,621	5,293	31.1	46.6	-15.5	-33
	Stripcropping only	156	231	24.5	30.4	-6.0	-20
	Terraces only	637	985	36.6	42.4	-5.8	-14
	All practices	7,741	11,853	33.1	45.8	-12.7	-28

Table 42 Effects of three conservation practices on estimates of nitrogen loss, sum of all loss pathways (lb/a/yr)—Continued

				Nitrogen loss			
Region	Conservation practices	Number of NRI sample points	Acres (1,000s)	Conservation-practices baseline scenario	No-practices scenario	Difference	Percent difference relative to no-practices scenario
Northern Great Plains	Contour farming only	268	365	39.7	44.1	-4.4	-10
	Contour farming and terraces	1,370	3,553	22.7	24.7	-2.0	-8
	Stripcropping only	602	1,945	12.9	13.2	-0.3	-2
	Terraces only	213	495	21.6	22.8	-1.2	-5
	All practices	2,453	6,357	20.6	22.1	-1.5	-7
Southern Great Plains	Contour farming only	104	235	48.4	49.6	-1.2	-2
	Contour farming and terraces	1,585	3,681	42.8	44.2	-1.4	-3
	Stripcropping only	80	149	42.6	42.9	-0.4	-1
	Terraces only	1,122	2,677	42.8	43.7	-0.9	-2
	All practices	2,891	6,743	43.0	44.1	-1.2	-3
West	Terraces only	72	58	27.2	28.5	-1.3	-4

Note: Results for conservation practices and combinations of practices based on less than 20 NRI sample points are not shown in the regional breakdowns, but these data are included in the aggregated results for all regions.

per acre per year, representing a reduction in nitrogen loss of about 7 pounds per acre. These model simulations suggest, therefore, that the conservation practices reported by the NRI reduce nitrogen loss by about 16 percent, on average, for acres with one of more of the three practices.

The bulk of the reductions in nitrogen loss resulted from reductions in waterborne sediment. Volatilization estimates were virtually the same for the two scenarios in all regions, and the practice effects on nitrogen lost with windborne sediment or dissolved in leachate or surface runoff were small in most regions. Estimates of nitrogen dissolved in leachate were typically higher for the baseline scenario than for the no-practices scenario, offsetting some of the overall nitrogen reductions obtained by reducing nitrogen lost with waterborne sediment. This is an expected result; these conservation practices are designed to slow the velocity of surface water runoff, which can lead to more percolation of water into the soil.

The largest reductions occurred for contour farming alone (10 lb/a/yr) and contour farming in combination with stripcropping (12 lb/a/yr). The most prevalent practice set—contour farming and terraces—reduced nitrogen loss estimates about 7 pounds per acre per year, on average. As observed for sediment loss, terraces only or stripcropping only resulted in the smallest reductions in nitrogen loss—about 2 pounds per acre per year on average.

The effects of conservation practices varied considerably by region (table 42). The largest nitrogen loss reductions occurred in the Northeast and Upper Midwest regions, which were also the regions with the highest sediment loss reductions attributable to the three conservation practices. Nitrogen loss reductions for acres with one or more of the three conservation practices in these two regions exceeded 10 pounds per acre per year, on average. The largest reduction in nitrogen loss was for the combination of contour farming and terraces in the Upper Midwest, which reduced nitrogen loss by 16 pounds per acre per year—33 percent.

Implications for reducing nitrogen loss with nutrient management practices

It is not possible to estimate the extent to which nutrient management practices may have reduced nitrogen loss estimates in these model simulations as done in the above sections for tillage practices and conservation practices, mostly because the available databases on nitrogen fertilizer applications did not identify operations that were complying with criteria for Nutrient Management Plans (NMP) and because the model inputs for nitrogen fertilizer were highly aggregated. Nevertheless, some insight into nitrogen loss reductions that may be possible with full implementation of NMP can be obtained by analyzing the results for the various application timing categories and application rate categories used to create the NNLSC database.

A subset of the NNLSC database was analyzed to answer two specific questions:

- If all crop producers adopted application times and rates associated with low nitrogen loss, what is the magnitude of the reduction in nitrogen loss that can be expected?
- What changes in the timing and application rates would be needed to achieve these expected reductions?

The approach taken to address these questions was to select from among the various nutrient management options represented in the database those that minimized nitrogen loss (sum of all loss pathways) for each URU and compare nitrogen loss estimates to those obtained for the full set of nutrient management options. Identifying the low nitrogen loss model runs within each URU guaranteed that all the major soil and climate conditions would be represented in the solution set.

Farmer surveys provided information for commercial fertilizer applications for nine crops included in the EPIC model simulations, representing nutrient management practices for 1990 to 1995 (see earlier section on representing commercial fertilizer applications in the model). A broad range of combinations of nitrogen application timing categories (fall, spring, at plant and after plant, and combinations) and nitrogen application rates (zero, low, medium, high) were simulated.

The scenario domain was restricted to the 9 crops (irrigated and non-irrigated)—corn for grain, soybeans, sorghum, winter wheat, spring wheat, cotton, rice, peanuts, and potatoes. Model runs with manure applications were excluded because manure application rates used in the model simulations were not obtained from farmer surveys. In addition, URUs with six or fewer nutrient management options were excluded to provide a reasonable amount of diversity among the nutrient management options within each URU. The resulting scenario domain consisted of 586,184 EPIC model runs for 14,699 URUs, representing 236 million cropland acres (about 80% of the full NNLSC database).

Two separate scenarios were constructed: 1) a nitrogen-reduction baseline scenario consisting of the full set of model runs in the domain described above, and 2) a minimum nitrogen loss scenario consisting of a subset of the model runs in the domain.

The minimum nitrogen loss scenario represents aggregate results for only the model runs within each URU that met criteria for minimum nitrogen loss. To select the minimum nitrogen loss nutrient management options, model runs were first grouped together for each tillage system (conventional tillage, mulch tillage, and no-till) within a URU. Separate sets of model runs were selected for each tillage system within a URU to avoid confounding the results with tillage effects. Model runs with crop yields less than 90 percent of the yield obtained for each URU-tillage grouping in the baseline scenario were discarded. This was done to prevent economically infeasible nutrient management options from being selected in the minimum nitrogen loss set. Because the nutrient management options were derived from farmer surveys, all would be expected to be economically feasible; however, some low (or no) nitrogen input options may not have been economically feasible as modeled. In some cases, low nitrogen use as reported in farmer surveys would have been associated with manure applications or crop rotations with legume crops in previous years. However, as this information was not available from the survey, some of the model simulations may have resulted in yields that were too low to be economically feasible.

Then, for each tillage subset within a URU, the model run having the lowest total nitrogen loss was identified, as well as all other model runs within that subset with nitrogen losses within 10 percent of the minimum. These model runs were used to represent the minimum nitrogen loss dataset. Application rates and timing categories associated with these model runs were used to define the nutrient management options associated with low nitrogen loss. Approximately 120,000 model runs—20 percent of the scenario domain—met the criteria for inclusion in the minimum nitrogen loss dataset.

Nitrogen loss summed over all loss pathways averaged 43 pounds per acre per year for the nitrogen-reduction baseline scenario, which was close to the 40 pounds per acre estimate for the full set of NRI sample points included in the study (table 43). Nitrogen loss for the minimum nitrogen loss scenario averaged 31 pounds per acre per year, 12 pounds per acre lower than the baseline. This result suggests that if all crop producers adopted application times and rates associated with low nitrogen loss, overall nitrogen loss might be reduced about 30 percent. The largest per-acre reduction in nitrogen loss—26 pounds per acre per year—would occur in the Southeast region, which had the highest per-acre nitrogen leaching loss estimates among the seven regions. The largest percent reduction in nitrogen loss would be expected in the West region, where the minimum nitrogen loss scenario had nitrogen loss estimates 62 percent lower than the baseline scenario. The smallest potential for nitrogen loss reductions occurred in the Upper Midwest and the Northern Great Plains regions. Of the crops included in the analysis, corn consistently showed the greatest potential for nitrogen loss reductions through improved timing of applications and lower application rates (table 43).

Most of the potential for nitrogen loss reductions—80 percent—was due to reductions in nitrogen volatilization and nitrogen dissolved in leachate in these model simulations (table 44). Overall, 52 percent of the potential nitrogen reduction was due to reductions in nitrogen volatilization. Over 75 percent of the potential for nitrogen reduction in the Northern Great Plains and the Southern Great Plains regions was due to reductions in nitrogen volatilization. On average, 28 percent of the potential for nitrogen loss reduction was due to reductions in nitrogen dissolved in leachate. In the Southeast region, about 60 percent of the potential for nitrogen loss reduction was due to reductions in nitrogen dissolved in leachate. This nitrogen loss pathway also accounted for over half of the potential nitrogen loss in the Northeast region. In the West region, the predominate loss pathway associated with potential nitrogen loss was nitrogen dissolved in surface water runoff.

Table 43 Nitrogen loss estimates (sum of all loss pathways) for the nitrogen-reduction baseline scenario and the minimum nitrogen loss scenario (lb/a/yr)

Region	Crop	Acres in baseline scenario (1,000s)	Baseline scenario	Minimum nitrogen loss scenario	Difference	Percent difference relative to baseline scenario
Northeast	All crops	4,250	53.2	37.1	-16.1	-30
Northern Great Plains	All crops	57,302	29.6	20.3	-9.3	-31
South Central	All crops	37,813	54.7	42.1	-12.7	-23
Southeast	All crops	9,191	81.7	55.6	-26.1	-32
Southern Great Plains	All crops	29,702	43.9	23.1	-20.8	-47
Upper Midwest	All crops	94,174	42	32.2	-9.9	-24
West	All crops	3,586	51.9	19.9	-32	-62
All regions	All crops	236,019	43.2	30.6	-12.6	-29
By crop within region*						
Northeast	Corn	2,889	54.2	34.4	-19.8	-37
	Soybeans	1,146	42.8	37.2	-5.6	-13
Northern Great Plains	Corn	15,425	52	31.6	-20.4	-39
	Spring wheat	18,720	22.1	15.4	-6.7	-30
	Sorghum	1,460	45.9	23.7	-22.2	-48
	Soybeans	9,351	24.2	23.6	-0.6	-2
	Winter wheat	12,156	13.9	10.1	-3.8	-27
South Central	Corn	5,899	60.8	32.5	-28.4	-47
	Cotton	5,487	47.6	28.2	-19.3	-41
	Peanuts	864	77.7	69.4	-8.4	-11
	Rice	3,004	77.9	49	-28.9	-37
	Sorghum	2,585	43.5	24.4	-19.1	-44
	Soybeans	12,607	63.1	61.7	-1.4	-2
	Winter wheat	7,367	32.7	26.5	-6.2	-19
Southeast	Corn	2,934	116.3	56.7	-59.5	-51
	Cotton	2,422	45.7	30.3	-15.4	-34
	Peanuts	470	81.1	71.2	-9.9	-12
	Soybeans	2,344	78.5	73.9	-4.6	-6
	Winter wheat	1,021	75.6	63.5	-12.1	-16
Southern Great Plains	Corn	2,645	64.3	27.2	-37.1	-58
	Cotton	7,306	39.5	25	-14.5	-37
	Peanuts	465	54.3	37.3	-17	-31
	Sorghum	4,497	59.5	23.9	-35.6	-60
	Winter wheat	14,767	37.4	20.8	-16.6	-44

Table 43 Nitrogen loss estimates (sum of all loss pathways) for the nitrogen-reduction baseline scenario and the minimum nitrogen loss scenario (lb/a/yr)—Continued

Region	Crop	Acres in baseline scenario (1,000s)	Baseline scenario	Minimum nitrogen loss scenario	Difference	Percent difference relative to baseline scenario
Upper Midwest	Corn	47,394	51.6	33.4	-18.2	-35
	Spring wheat	815	29.5	21.1	-8.4	-28
	Sorghum	1,471	33.8	21.9	-11.9	-35
	Soybeans	39,649	32.4	32	-0.4	-1
	Winter wheat	4,720	28	25.8	-2.1	-8
West	Cotton	1,631	52	10.6	-41.4	-80
	Potatoes	323	109.5	42.8	-66.7	-61
	Winter wheat	1,435	32.5	21.8	-10.7	-33

Note: Results for crops within regions with less than 250,000 acres are not shown, but these data are included in the aggregated results by region.

Table 44 Nitrogen loss reductions (nitrogen loss estimates for the nitrogen-reduction baseline scenario minus the minimum nitrogen loss scenario) for each nitrogen loss pathway (lb/a/yr)

Region	Dissolved in surface water runoff	Dissolved in leachate	Dissolved in lateral subsurface flow	Volatilization	Lost with waterborne sediment	Lost with windborne sediment	Sum of all loss pathways
Northeast	0.89	8.56	0.43	3.53	2.67	0.06	16.1
Northern Great Plains	0.67	0.74	0.17	7.05	0.30	0.33	9.3
South Central	2.18	5.45	0.13	3.59	1.26	0.08	12.7
Southeast	0.99	15.59	0.28	8.23	1.00	0.00	26.1
Southern Great Plains	0.91	2.85	0.16	15.75	0.24	0.87	20.8
Upper Midwest	0.50	3.48	0.16	4.36	1.30	0.06	9.9
West	19.47	1.92	0.22	10.26	0.11	0.03	32.0
All regions	1.18	3.59	0.17	6.55	0.91	0.23	12.6

What changes in the timing and application rates would be needed to achieve these expected reductions? In this analysis, the potential for nitrogen loss reduction was determined by the set of model runs associated with low nitrogen loss. This set of model runs represented a different mix of application rate categories and application timing categories than in the baseline scenario. The difference in the mix between the two scenarios is an indication of some of the changes in current nutrient management practices that would be necessary to realize the potential for nitrogen loss reductions reported.

The mix of application rate and timing categories for the two scenarios can be represented by the proportion of model runs in each category (table 45). Comparing the mix of application rate and timing categories in the two scenarios indicates that nitrogen loss reductions could be achieved by:

- Reducing the nitrogen application rates for producers with rates in the top third (the high rate category) to rates similar to the lower rates used by the other two-thirds of producers. In the minimum nitrogen loss scenario, only 6 percent of the model runs had application rates in the high rate category and 44 percent had application rates in the low rate category, whereas in the baseline scenario the three application rate categories were about equally represented.
- Reducing the occurrence of fall applications of nitrogen wherever possible. In the baseline scenario, 37 percent of the model runs included a fall application, compared to only 24 percent for the minimum nitrogen loss scenario.

Table 45 Percentage of model runs in each application rate and timing category for the nitrogen-reduction baseline scenario and the minimum nitrogen loss scenario

Category	Percent of model runs in the minimum nitrogen loss scenario	Percent of model runs in the baseline scenario
Application rate categories*		
High nitrogen rates	6.7	31.2
Medium nitrogen rates	32.5	32.5
Low nitrogen rates	44.0	30.7
No nitrogen applications	16.8	5.7
All categories	100.0	100.0
Application timing categories**		
Spring before plant only	22.8	20.8
At plant only	22.5	11.1
After plant only	17.5	12.9
Fall only	18.1	22.7
Fall and spring	0.2	2.6
Fall and at plant	1.1	4.7
Fall and after plant	4.2	7.3
Spring and at plant	2.6	6.8
Spring and after plant	3.2	4.3
At plant and after plant	7.6	6.8
All categories	100.0	100.0

* High, medium, and low application rate categories were derived from the farmer surveys and represent different rates for each crop and state. The high category is based on the highest third of the application rates in the survey sample and the low category is based on the lowest third of the application rates in the survey sample for each crop and state (see section on representing commercial fertilizer applications in the model).

** Excludes occurrences of no nitrogen applications

- Replacing fall applications with applications at plant or applications after plant. In the minimum nitrogen loss scenario, 40 percent of the model runs were for applications either at plant or after plant, compared to 24 percent for the baseline scenario.
- Reducing the occurrence of nitrogen applications in multiple time periods. In the minimum nitrogen loss scenario, 81 percent of the model runs were for applications in only one time period, compared to 67 percent for the baseline scenario.

Assessment of critical acres for nitrogen loss

Three of the six nitrogen loss pathways are used to identify critical acres for nitrogen loss:

- nitrogen lost with waterborne sediment
- nitrogen dissolved in surface water runoff
- nitrogen dissolved in leachate

Nitrogen loss from volatilization was not used to identify critical acres because loss estimates were high for nearly all cropland acres; identification of the highest subsets tends to reinforce critical acres identified by other measures rather than define additional acres with resource concerns. Nitrogen lost with windborne sediment is well represented by critical acres identified for wind erosion. Nitrogen loss dissolved in lateral subsurface flow had levels too low to be useful as a criterion for identifying critical acres.

Specific regions of the country have been shown in this study to have a much higher potential for nitrogen loss from one of these three nitrogen loss pathways than other areas of the country. Moreover, as shown in maps 17, 19, and 20 and in the example for the two Iowa watersheds, nitrogen loss estimates often varied considerably within relatively small geographic areas. Estimates of the average nitrogen loss by region and by crops within regions mask much of this underlying variability. Tables 46 through 48 demonstrate the extent of both regional and local variability by presenting the percentiles for each of the three nitrogen loss pathways for each region.

For nitrogen lost with waterborne sediment, the mean of the distribution exceeded the median for all regions (table 46), indicating that the bulk of the nitrogen loss estimates for this pathway is below the average and that there is a minority of sample points with very high loss estimates. This disproportionality was pronounced for three regions—the Northeast, the Southeast, and the West. For all regions, loss estimates for acres at or above the 90th percentile threshold were over twice the average. In the Southeast and the West, the mean was nearly the same as or exceeded the 75th percentile.

All regions exhibited strong disproportionality for nitrogen dissolved in leachate and dissolved in surface water runoff (tables 47 and 48). The mean for nitrogen dissolved in surface water runoff (3.8 lb/a/yr) was over twice that of the 50th percentile (1.7 lb/a/yr) for all acres included in the study. The mean for nitrogen dissolved in leachate (6.7 lb/a/yr) was over six times that of the 50th percentile (1.1 lb/a/yr) and exceeded the 75th percentile for all cropland acres included in the study.

Five categories of critical acres for nitrogen lost with waterborne sediment, representing different degrees of severity, are defined on the basis of national level results:

- acres where per-acre nitrogen loss is above the 95th percentile for all acres included in the study (26.597 lb/a/yr)
- acres where per-acre nitrogen loss is above the 90th percentile for all acres included in the study (19.425 lb/a/yr)
- acres where per-acre nitrogen loss is above the 85th percentile for all acres included in the study (16.181 lb/a/yr)
- acres where per-acre nitrogen loss is above the 80th percentile for all acres included in the study (13.518 lb/a/yr)
- acres where per-acre nitrogen loss is above the 75th percentile for all acres included in the study (11.733 lb/a/yr)

Five categories of critical acres for nitrogen dissolved in surface water runoff were defined in a similar manner:

- acres where per-acre nitrogen loss is above the 95th percentile for all acres included in the study (12.863 lb/a/yr)

Table 46 Percentiles of nitrogen lost with waterborne sediment (lb/a/yr)

Region	Acres	Number of NRI sample points	Mean	5th percentile	10th percentile	25th percentile	50th percentile	75th percentile	90th percentile	95th percentile
Northeast	13,641,900	11,282	13.362	0.000	0.000	0.100	4.604	20.742	38.225	52.145
Northern Great Plains	72,396,500	36,035	4.543	0.020	0.189	1.029	4.143	6.453	9.124	12.974
South Central	45,349,900	27,465	10.935	0.059	0.810	5.054	9.122	14.346	21.351	27.629
Southeast	13,394,400	8,955	7.108	0.025	0.072	0.518	2.978	7.265	16.176	24.177
Southern Great Plains	32,096,000	14,495	2.555	0.082	0.350	0.804	1.965	3.492	5.618	7.475
Upper Midwest	112,580,900	74,691	11.816	0.013	0.221	5.007	9.658	16.144	24.649	32.286
West	9,018,400	5,644	2.726	0.000	0.000	0.036	0.306	1.147	10.168	14.110
All regions	298,478,000	178,567	8.507	0.014	0.116	1.597	5.773	11.733	19.425	26.597

Note: Percentiles are in terms of acres. The 5th percentile, for example, is the threshold below which 5 percent of the acres have lower loss estimates.

Table 47 Percentiles of nitrogen dissolved in surface water runoff (lb/a/yr)

Region	Acres	Number of NRI sample points	Mean	5th percentile	10th percentile	25th percentile	50th percentile	75th percentile	90th percentile	95th percentile
Northeast	13,641,900	11,282	6.638	1.096	1.429	2.534	5.276	8.687	14.344	16.403
Northern Great Plains	72,396,500	36,035	1.794	0.094	0.168	0.396	1.008	2.425	4.357	5.641
South Central	45,349,900	27,465	7.700	0.581	0.947	2.352	5.103	9.450	13.736	31.077
Southeast	13,394,400	8,955	3.970	0.259	0.585	1.312	2.716	5.553	9.076	11.345
Southern Great Plains	32,096,000	14,495	1.706	0.047	0.093	0.161	0.515	2.348	4.848	6.906
Upper Midwest	112,580,900	74,691	2.834	0.586	0.671	0.957	1.489	3.126	7.530	9.341
West	9,018,400	5,644	15.973	0.168	0.280	1.715	11.037	25.750	44.273	50.443
All regions	298,478,000	178,567	3.822	0.149	0.327	0.802	1.721	4.396	8.961	12.863

Note: Percentiles are in terms of acres. The 5th percentile, for example, is the threshold below which 5 percent of the acres have lower loss estimates.

Table 48 Percentiles of nitrogen dissolved in leachate (lb/a/yr)

Region	Acres	Number of NRI sample points	Mean	5th percentile	10th percentile	25th percentile	50th percentile	75th percentile	90th percentile	95th percentile
Northeast	13,641,900	11,282	6.811	0.053	0.094	0.306	1.599	8.783	18.757	24.755
Northern Great Plains	72,396,500	36,035	1.018	0.000	0.000	0.000	0.000	0.149	2.115	6.256
South Central	45,349,900	27,465	13.417	0.061	0.150	1.447	8.142	19.231	34.986	46.239
Southeast	13,394,400	8,955	29.907	0.039	0.106	1.510	16.393	36.588	59.228	78.240
Southern Great Plains	32,096,000	14,495	3.826	0.000	0.000	0.045	0.681	3.356	11.710	20.150
Upper Midwest	112,580,900	74,691	6.025	0.016	0.075	0.518	1.965	5.485	15.391	25.881
West	9,018,400	5,644	2.284	0.000	0.000	0.001	0.085	0.628	4.188	7.825
All regions	298,478,000	178,567	6.692	0.000	0.000	0.051	1.094	6.069	18.902	31.454

Note: Percentiles are in terms of acres. The 5th percentile, for example, is the threshold below which 5 percent of the acres have lower loss estimates.

- acres where per-acre nitrogen loss is above the 90th percentile for all acres included in the study (8.961 lb/a/yr)
- acres where per-acre nitrogen loss is above the 85th percentile for all acres included in the study (7.046 lb/a/yr)
- acres where per-acre nitrogen loss is above the 80th percentile for all acres included in the study (5.413 lb/a/yr)
- acres where per-acre nitrogen loss is above the 75th percentile for all acres included in the study (4.396 lb/a/yr)

Five categories of critical acres for nitrogen dissolved in leachate were defined in a similar manner:

- acres where per-acre nitrogen loss is above the 95th percentile for all acres included in the study (31.454 lb/a/yr)
- acres where per-acre nitrogen loss is above the 90th percentile for all acres included in the study (18.902 lb/a/yr)
- acres where per-acre nitrogen loss is above the 85th percentile for all acres included in the study (12.674 lb/a/yr)
- acres where per-acre nitrogen loss is above the 80th percentile for all acres included in the study (8.659 lb/a/yr)
- acres where per-acre nitrogen loss is above the 75th percentile for all acres included in the study (6.069 lb/a/yr)

The regional representation of critical acres is shown in tables 49–51 for each of the five categories. About 95 percent of the acres with per-acre estimates of nitrogen lost with waterborne sediment in the top 5 percent were in three regions—the Upper Midwest region (60% of critical acres), the South Central region (17% of critical acres), and the Northeast region (17% of critical acres). These are the same three regions with most of the critical acres for sediment loss.

For nitrogen dissolved in surface water runoff, the South Central (34%) and West (28%) regions had the majority of acres in the top 5 percent. As the criterion for critical acres expanded from the top 5 percent to the top 25 percent, the Upper Midwest replaced the West as the region with the second highest number of critical acres for nitrogen dissolved in surface water runoff.

For nitrogen dissolved in leachate, three regions had about 90 percent of the critical acres in the top 5 percent category—the South Central region (37%), the Southeast (27%) and the Upper Midwest (26%). In the Northeast region, over half of the cropland acres were designated as critical acres in the top 25 percent nationally for nitrogen dissolved in surface water runoff. In the South Central region, over half of the cropland acres were designated as critical acres in the top 25 percent nationally for both nitrogen dissolved in surface water runoff and nitrogen dissolved in leachate. In the Southeast region, two-thirds of the cropland acres were critical acres in the top 25 percent nationally for nitrogen dissolved in leachate.

These critical acres accounted for the bulk of the 570,341 tons per year of nitrogen dissolved in surface water runoff, 998,637 tons per year of nitrogen dissolved in leachate, and the 1,269,517 tons per year of nitrogen lost with waterborne sediment. The 95th percentile category, representing the 5 percent of acres with the highest per-acre losses, accounted for 32 percent of the total tons of nitrogen dissolved in surface water runoff, 44 percent of the total tons of nitrogen dissolved in leachate, and 23 percent of the total tons of nitrogen lost with waterborne sediment. The 25 percent of acres with the highest per-acre losses accounted for 71 percent of the total tons of nitrogen dissolved in surface water runoff, 87 percent of the total tons of nitrogen dissolved in leachate, and 63 percent of the total tons of nitrogen lost with waterborne sediment.

Percentile	Percent of total tons of nitrogen dissolved in leachate	Percent of total tons of nitrogen dissolved in surface water runoff	Percent of total tons of nitrogen lost with waterborne sediment
95th	44.3	32.4	23.3
90th	62.5	46.3	36.7
85th	74.1	56.7	47.0
80th	81.9	64.8	55.7
75th	87.4	71.2	63.1

Table 49 Critical areas for nitrogen lost with waterborne sediment

		Per-acre loss in top 5% nationally		Per-acre loss in top 10% nationally		Per-acre loss in top 15% nationally		Per-acre loss in top 20% nationally		Per-acre loss in top 25% nationally	
Region	Acres	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent
Northeast	13,641,900	2,593,100	17.4	3,556,000	11.9	4,142,600	9.3	4,712,700	7.9	5,079,100	6.8
Northern Great Plains	72,396,500	71,600	0.5	359,500	1.2	1,966,500	4.4	3,253,400	5.4	4,087,900	5.5
South Central	45,349,900	2,562,200	17.2	5,976,300	20.0	8,858,100	19.8	12,843,200	21.5	16,342,900	21.9
Southeast	13,394,400	593,200	4.0	1,047,900	3.5	1,331,600	3.0	1,625,300	2.7	2,100,900	2.8
Southern Great Plains	32,096,000	0	0.0	0	0.0	62,700	0.1	212,200	0.4	293,300	0.4
Upper Midwest	112,580,900	8,940,800	59.9	18,626,700	62.4	28,068,500	62.7	36,606,200	61.3	46,082,500	61.7
West	9,018,400	153,200	1.0	289,900	1.0	342,000	0.8	467,600	0.8	643,000	0.9
All regions	298,478,000	14,914,100	100.0	29,856,300	100.0	44,772,000	100.0	59,720,600	100.0	74,629,600	100.0

Note: The top 5 percent corresponds to the 95th percentile in table 46. Other columns correspond to table 46 in a similar manner.

Table 50 Critical areas for nitrogen dissolved in surface water runoff

		Per-acre loss in top 5% nationally		Per-acre loss in top 10% nationally		Per-acre loss in top 15% nationally		Per-acre loss in top 20% nationally		Per-acre loss in top 25% nationally	
Region	Acres	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent
Northeast	13,641,900	1,977,100	13.2	3,259,000	10.9	4,599,900	10.3	6,622,900	11.1	8,076,400	10.8
Northern Great Plains	72,396,500	270,800	1.8	985,600	3.3	2,142,900	4.8	3,967,600	6.6	7,118,200	9.5
South Central	45,349,900	5,090,100	34.1	12,005,100	40.3	16,726,900	37.4	21,835,300	36.6	25,260,500	33.9
Southeast	13,394,400	363,900	2.4	1,377,200	4.6	2,195,600	4.9	3,417,300	5.7	4,394,600	5.9
Southern Great Plains	32,096,000	302,100	2.0	625,300	2.1	1,556,100	3.5	2,545,900	4.3	3,756,500	5.0
Upper Midwest	112,580,900	2,673,300	17.9	6,733,700	22.6	12,512,300	28.0	16,022,200	26.8	20,485,500	27.5
West	9,018,400	4,247,100	28.5	4,796,400	16.1	5,014,700	11.2	5,277,700	8.8	5,516,200	7.4
All regions	298,478,000	14,924,400	100.0	29,782,300	100.0	44,748,400	100.0	59,688,900	100.0	74,607,900	100.0

Note: The top 5 percent corresponds to the 95th percentile in table 47. Other columns correspond to table 47 in a similar manner.

Table 51 Critical areas for nitrogen dissolved in leachate

Region	Acres	Per-acre loss in top 5% nationally		Per-acre loss in top 10% nationally		Per-acre loss in top 15% nationally		Per-acre loss in top 20% nationally		Per-acre loss in top 25% nationally	
		Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent
Northeast	13,641,900	450,400	3.0	1,360,000	4.6	2,200,700	4.9	3,498,200	5.9	4,358,800	5.8
Northern Great Plains	72,396,500	301,900	2.0	619,000	2.1	1,292,400	2.9	2,143,300	3.6	3,710,600	5.0
South Central	45,349,900	5,495,400	36.8	11,547,500	38.7	16,521,200	36.9	21,766,800	36.5	25,460,800	34.1
Southeast	13,394,400	4,030,100	27.0	6,057,500	20.3	7,584,200	16.9	8,240,600	13.8	8,824,200	11.8
Southern Great Plains	32,096,000	577,500	3.9	1,779,600	6.0	3,026,800	6.8	4,778,400	8.0	5,521,200	7.4
Upper Midwest	112,580,900	3,899,600	26.1	8,252,000	27.7	13,816,000	30.9	18,858,400	31.6	26,025,500	34.9
West	9,018,400	171,300	1.1	227,200	0.8	329,200	0.7	409,100	0.7	716,100	1.0
All regions	298,478,000	14,926,200	100.0	29,842,800	100.0	44,770,500	100.0	59,694,800	100.0	74,617,200	100.0

Note: The top 5 percent corresponds to the 95th percentile in table 48. Other columns correspond to table 48 in a similar manner.