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Estimates of County-Level Nitrogen and Phosphorus from Fertilizer and Manure from 1950 through 2017 in the Conterminous United States

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U.S. Department of the Interior
U.S. Geological Survey

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By James A. Falcone

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	247.1	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Mass	
kilogram (kg)	2.205	pound, avoirdupois (lb)

Abbreviations

AAPFCO	Association of American Plant Food Control Officials
CDL	Cropland Data Layer, a national 30-meter cropland raster dataset
CoA	Census of Agriculture
CONUS	conterminous United States
ERS	Economic Research Service [of the U.S. Department of Agriculture]
FPI	fertilizer price index
kg	kilograms
km	kilometers
N	nitrogen
NHDPlus	National Hydrography Dataset Plus
P	phosphorus
RF	random forests
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

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Abstract

This report and associated dataset provide tabular county-level estimates of kilograms of nitrogen and phosphorus generated from two sources: (a) fertilizer from commercial sources and (b) livestock-based manure, for the period 1950 through 2017 for the conterminous United States. Datasets collected during this time span are for intervals of approximately 5 years that coincide with the U.S. Department of Agriculture's census years. Nutrients from fertilizer for 1950–2012 are exactly those previously described in U.S. Geological Survey (USGS) reports and datasets; however, estimates of nutrient masses from fertilizer applied in 2017 are described here as a new product modeled from 11 predictor variables for 2017 including county-level fertilizer expenditures, land use, and acres of fertilized land. Fertilizer-based estimates are provided for both farm and nonfarm (urban) usage. The estimates of nutrients from manure for all years were generated anew by using methods and formulas described in previous USGS reports but adjusted to account for historical changes in the annual averages of animal weights. The tabular data are available as an accompanying data release.

Introduction

Estimates of nutrient input to the environment from human activities are needed for various scientific and research activities—for example, the study of water quality in streams and rivers (Gronberg and Spahr, 2012). To conduct ongoing water-quality studies, the U.S. Geological Survey (USGS) National Water-Quality Project currently has a need for estimates of masses of constituents at the finest spatial resolution feasible for the period 1950–2017. The input of nutrients to the environment comes in large part from the (a) use of commercial fertilizer, primarily for agricultural purposes, and the (b) use of manure from livestock. These are the two categories for which nutrient data, nitrogen (N) and phosphorus (P), are given in this report. The purpose of this dataset is to provide a 1950–2017 time series for nutrients from both fertilizer and manure; the data in this series are intended to be as consistent as is possible with data in previous USGS publications. In this report, the term "fertilizer" refers to commercially purchased fertilizer, differentiating it from livestock manure.

Previous U.S. Geological Survey Publications Estimating Nutrients from Commercial Fertilizer

Previous USGS reports have published county-level estimates of nutrients from commercial fertilizer for earlier periods. These include Alexander and Smith (1990) for the years 1945–1985; Battaglin and Goolsby (1995) for the years 1985–1991; Ruddy and others (2006) for the years 1987–2001; Gronberg and Spahr (2012) for the years 1987–2006; and Brakebill and Gronberg (2017) for the years 2007–2012 (fig. 1). Gronberg and Spahr (2012) revised the method used by Ruddy and others (2006) and published revised data for 1987–2001. (And for convenience, Brakebill and Gronberg (2017) republished the 1987–2006 data from Gronberg and Spahr (2012), so that the entire period 1987–2012 was available in one location). All of these previous efforts provided county-level estimates of nutrients in kilograms for annual periods within the conterminous United States (CONUS). The Alexander and Smith (1990) and Battaglin and Goolsby (1995) datasets provided estimates only for total nutrient inputs, that is, for the combination of agriculture (farm) and urban (nonfarm) sources. The later (2006, 2007, 2012, 2017) datasets separated nutrient inputs from farm- and nonfarm-fertilizer sources. Most fertilizer use, by a large margin, is for agricultural purposes in the United States. For example, in 2012, 98 percent of nitrogen from fertilizer was from farm use, and 2 percent was from nonfarm use (Brakebill and Gronberg, 2017).

For nutrient estimates based on fertilizer data, the previously developed nutrient datasets (fig. 1) provide a reasonably consistent time series for the years 1950–2012. Therefore, estimates of nutrient mass only for 2017 needed to be generated for this report.

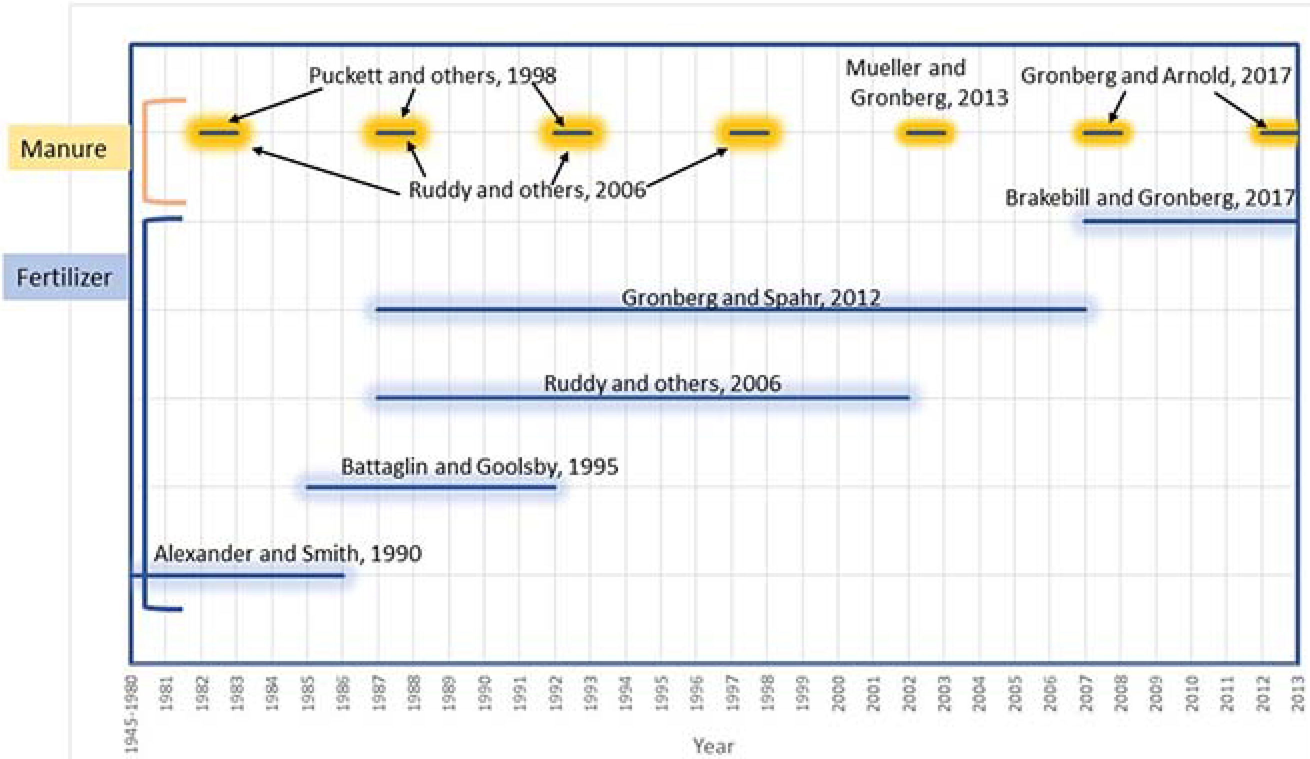

Figure 1. Timeline for previous U.S. Geological Survey county-level nutrient datasets for the conterminous United States.

Previous datasets all used the same basic method: county fertilizer expenditures were estimated by obtaining State-level-use estimates in tons of nutrient mass. These data were then apportioned to counties on the basis of the proportion of county fertilizer expenditures (Battaglin and Goolsby, 1995; Ruddy and others, 2006; Gronberg and Spahr, 2012; Brakebill and Gronberg, 2017) or by dividing the most recent use estimates for that year based on the U.S. Department of Agriculture (USDA) Census of Agriculture data by the number of fertilized acres in each county (Alexander and Smith, 1990; Gronberg and Spahr, 2012). Every Census of Agriculture survey includes the number of dollars spent on fertilizer by county, as well as the number of acres on which commercial fertilizer was used but does not include amounts of nutrients by mass. For example, if it was known that a State had used 1,000 kilograms of nitrogen from fertilizer sales for year 2003, and if a county within that State had used 2 percent of the State's fertilizer expenditures in dollars in the 2002 Census of Agriculture (nearest point in time to 2003), then that county would be assigned a value of 20 kilograms of nitrogen for 2003 (1,000 × 0.02). Since 1987, USGS fertilizer estimates have been based on State-level mass statistics for tonnages of commercially produced fertilizer as compiled by the Association of American Plant Food Control Officials (AAPFCO, www.aapfco.org), which also generally provides statistics for farm compared to nonfarm usage. The AAPFCO data for 2017, however, have not been completed (J. Slater, University of Missouri, written commun., May 4, 2020), nor are other State-level summaries of fertilizer use by weight available. As a result, at the present time (2020), use of the method described above is not feasible for 2017 data.

An alternate method for estimating the mass of nutrients from fertilizer is given by Stewart and others (2019), who used nine predictor variables in a regression against AAPFCO-derived data to estimate mass of nitrogen and phosphorus at the scale of National Hydrography Dataset Plus (NHDPlus) catchments (McKay and others, 2012) for the year 2012. These predictor variables were county-level fertilizer expenditures in dollars from the Census of Agriculture, masses of nitrogen or phosphorus from manure, percentages of land surfaces in five agricultural-crop groups, precipitation, and actual evapotranspiration. A modification of the Stewart and others (2019) method was used here as described in the Methods section.

Previous USGS Publications Estimating Nutrients from Manure

Like estimates of nutrients from fertilizer, estimates of nitrogen and phosphorus nutrients from manure (livestock waste) have been published in previous USGS reports. These estimates were produced for 5-year increments in units of kilograms per county. These reports include Puckett and others (1998) for the years 1982, 1987, and 1992; Ruddy and others (2006) for the years 1982, 1987, 1992, and 1997;

Table 1. Availability and sources of data compiled in this report.

[N, nitrogen; P, phosphorus; —, no data entered]

Year	N and P from combined farm and nonfarm fertilizer	N and P from farm fertilizer	N and P from nonfarm fertilizer	N and P from manure
1950	Yes[1]	—	—	Yes[4]
1954	Yes[1]	—	—	Yes[4]
1959	Yes[1]	—	—	Yes[4]
1964	Yes[1]	—	—	Yes[4]
1969	Yes[1]	—	—	Yes[4]
1974	Yes[1]	—	—	Yes[4]
1978	Yes[1]	—	—	Yes[4]
1982	Yes[1]	—	—	Yes[4]
1987	—	Yes[2]	Yes[2]	Yes[4]
1992	—	Yes[2]	Yes[2]	Yes[4]
1997	—	Yes[2]	Yes[2]	Yes[4]
2002	—	Yes[2]	Yes[2]	Yes[4]
2007	—	Yes[3]	Yes[3]	Yes[4]
2012	—	Yes[3]	Yes[3]	Yes[4]
2017	—	Yes[4]	Yes[4]	Yes[4]

[1]From Alexander and Smith (1990).

[2]From Gronberg and Spahr (2012).

[3]From Brakebill and Gronberg (2017).

[4]From Falcone (2021).

Mueller and Gronberg (2013) for year 2002; and Gronberg and Arnold (2017) for the years 2007 and 2012 (fig. 1). All of these previously published manure-based nutrient estimates rely on source data from the Census of Agriculture—namely county-level livestock populations of cows, hogs, poultry, sheep, and horses. A consistent set of formulas for calculating nutrient content was used by Gronberg and Arnold (2017), Mueller and Gronberg (2013), and Ruddy and others (2006), which were in turn taken from Goolsby and others (1999). Census of Agriculture data have been collected at approximate 5-year intervals since the 1800s, including the years 1950, 1954, 1959, 1964, 1969, 1974, 1978, 1982, 1987, 1992, 1997, 2002, 2007, 2012, and 2017—the years whose data were used for this project. Because Census of Agriculture livestock data are reasonably consistent over this period and were largely normalized by LaMotte (2015), a complete time series could be provided for all years.

In summary, this dataset provides (a) county-level estimates of kilograms of nitrogen and phosphorus from commercial fertilizer applied to land for the Census of Agriculture years from 1950 through 2017 and (b) county-level estimates of kilograms of nitrogen and phosphorus from animal manure for those same years. Table 1 lists the availability and sources of data in this report by year. The data themselves are published as two tabular datasets linked in a USGS data release (Falcone, 2021).

Methods

Methods are given in this section for the calculation of masses of nutrients from (a) fertilizer and (b) manure. In both cases, the masses of nutrients derived are for nitrogen and phosphorus.

Method for Producing Nutrient Estimates from Farm Fertilizer in 2017

The method used for estimating the mass of nutrients from farm fertilizer in 2017 followed the basic approach used by Stewart and others (2019), which was to estimate the masses of nutrients from landscape variables and Census of Agriculture fertilizer information. Stewart and others (2019) estimated masses of nutrients at the National Hydrography Dataset Plus (NHDPlus) catchment scale, whereas this method uses estimates at the county scale. Stewart and others (2019) used nine predictor variables—namely, five categories of crop types, county fertilizer expenditures, and the masses of the nutrients from manure, precipitation, and evapotranspiration (table 2). This report uses the same nine variables plus two additional ones: the number of fertilized acres in the county and the population density. Stewart and others (2019) used a nonlinear least-squares method to estimate coefficients to relate the predictor variables to the known masses of nutrients. This method used random forests (RF) (Breiman, 2001) decision-tree models, one each for nitrogen and phosphorus. The estimation was modeled in the R computing environment (R Core Team, 2019).

The 11 predictor variables were assembled from the sources given in table 2. Crop data were obtained from LaMotte (2015) for years prior to 2017, and 2017 data for the same variables were retrieved from the USDA Quick Stats tool (U.S. Department of Agriculture, 2020a). As described in Stewart and others (2019), dollar values for fertilizer expenditures were adjusted by dividing by the fertilizer-price index for each year to normalize dollar values to buying power. Fertilizer-price index (FPI) values were obtained from the USDA (2019, “Index of prices paid by farmers”). For consistency, the set of county entities used included the 3,066 counties compiled by LaMotte (2015), because data used in other parts of this project (nutrients from manure) were derived from those same counties.

Table 2. Variables used in county-level predictions of masses of nutrients from 2017 farm fertilizer.

[CoA, Census of Agriculture; USDA, U.S. Department of Agriculture; pct, percentage]

Variable name	Variable description	Unit	Source
CoAcornpct[1]	Percentage of corn crops (from CoA)	Percentage of county area	LaMotte (2015), USDA (2020a)
CoApasturepct[1]	Percentage of pasture crops (from CoA)	Percentage of county area	LaMotte (2015), USDA (2020a)
CoAnitrogenfixpct[1]	Percentage of nitrogen-fixing crops (from CoA)	Percentage of county area	LaMotte (2015), USDA (2020a)
CoAsmallgrainpct[1]	Percentage of small-grain crops (from CoA)	Percentage of county area	LaMotte (2015), USDA (2020a)
CoAmiscpct[1]	Percentage of miscellaneous crops (from CoA)	Percentage of county area	LaMotte (2015), USDA (2020a)
fertdolFPI[2]	Dollars spent on fertilizer (from CoA) divided by fertilizer-price index	Dollars	LaMotte (2015), USDA (2020a), USDA (2020b)
manureTotalkg	Kilograms of manure for nitrogen or phosphorus	Kilograms	Mueller and Gronberg (2013), Gronberg and Arnold (2017), Falcone (2021)
ET	Evapotranspiration, annual	Millimeters	U.S. Geological Survey (2020)
PPT	Precipitation, annual	Millimeters	PRISM Climate Group (2020)
fertacres[3]	Fertilized acres (from CoA)	Number of acres	LaMotte (2015), USDA (2020a)
pden[3]	Population density[4]	Persons per square kilometer	Manson and others (2019)

[1]Specific crops within each of the crop groups were described by Stewart and others (2019).

[2]Fertilizer-price index values used were 0.328 for 2002, 0.656 for 2007, 1.014 for 2012, and 0.662 for 2017 (USDA, 2020b).

[3]Numbers of fertilized acres and population-density numbers were not used by Stewart and others (2019).

[4]Population-density numbers were obtained from the National Historical Geographic Information System site (Manson and others, 2019) for 2000, 2010, and 2017 and interpolated for 2002, 2007, and 2012.

For each RF model (one for nitrogen and one for phosphorus), the model was constructed by assembling data for known county-level masses of nutrients published by Brakebill and Gronberg (2017) for the most recent 3 years prior to 2017 for which Census of Agriculture data existed: 2002, 2007, and 2012. These RF models resulted in 9,198 training records (3,066 counties × 3 years). For each of these records, values of the 11 predictor variables for the same years were also assembled. These values were then used as input into the RF model as a regression. This created a model that could predict the mass of the nutrient on the basis of the 11 predictors. RF models do this by creating an ensemble decision tree (making a figurative forest of trees) by testing random variations of variables (table 3) to find the best fit at each tree node (Liaw and Wiener, 2002). In this effort, it was found that the results were largely insensitive to the number of trees used, and the final models were produced with 1,000 trees.

Once a model was created for nitrogen and for phosphorus, the model was then applied to the 2017 values of the 11 predictors for the 3,066 counties, each of which produced estimates of kilograms of nitrogen and phosphorus from farm fertilizer. In RF decision-tree modeling, how well the model performs for a given tree is measured by withholding subsets of records from that tree at each iteration. The proportion of variance explained (r^2) reported for the nitrogen model with 1,000 trees was 0.948 and for the phosphorus model was 0.921. By far, the most important variable for predicting the masses of both nitrogen and phosphorus was the county fertilizer expenditure in dollars (table 3). Stewart and others (2019) similarly reported this variable as having the most predictive power within their model.

Method for Producing Nutrient Estimates from Nonfarm Fertilizers for 2017

As noted above, only about 2 percent of nutrients come from nonfarm-fertilizer uses in the United States; however, for urban counties, the nonfarm-fertilizer percentage may be much greater. Publications used since 1987 have relied on AAPFCO indications of farm compared to nonfarm usage; however, those data were not available for 2017. To estimate nutrient mass from nonfarm fertilizer usage (urban usage), nonfarm fertilizer usage values were related to population counts from previous years, and these ratios were then applied to 2017. First, the populations by county were assembled for the years 2000, 2010, and 2017 (Manson and others, 2019). The 2017 data are from the Census American Community Survey, a rolling census of statistically sampled households, which provide data for interdecadal years. The numbers of kilograms of nitrogen and phosphorus from sources other than farms for the years 2000 and 2010 were taken from Brakebill and Gronberg (2017), and a ratio of kilograms of nitrogen and phosphorus per person was calculated for those 2 years. The average of the 2000 and 2010 kilogram-per-person ratios was then applied to the 2017 population count for each county and nutrient, providing estimates of nonfarm nutrient masses of nitrogen and phosphorus for 2017. For example, if a county had a population of 50,000 in 2000, 55,000 in 2010, and 60,000 in 2017, and had 15,000 kilograms of phosphorus in 2000 and 12,000 kilograms of phosphorus in 2010, the calculation for the 2017 estimate would be: (((15,000/50,000) + (12,000/55,000)) / 2) × 60,000 = 15,545 kilograms of nonfarm phosphorus.

Table 3. Variable importance reported by random forests for 2017 nitrogen and phosphorus farm-fertilizer models.

[%IncMSE, the percent increase in mean square error if the variable is removed from the decision tree. Higher values indicate more importance in successful prediction. Variables defined in table 2]

Variable	%IncMSE, nitrogen model	%IncMSE, phosphorus model
CoAcornpct	23.0	22.5
CoApasturepct	24.7	26.7
CoAnitrogenfixpct	20.7	27.6
CoAsmallgrainpct	15.4	13.3
CoAmiscpct	19.3	18.7
fertdolFPI	73.3	67.7
manureTotalkg	15.9	13.9
ET	22.1	20.8
PPT	22.1	20.8
fertacres	34.9	28.3
pden	22.4	20.4

Nutrients from Manure

This section describes the estimation of nutrient mass from livestock manure by county for the years 1950 through 2017. The method used here was identical to that used by Gronberg and Arnold (2017) (which was, in turn, similar to methods used in other USGS reports) with two modifications: how data withheld by the Census of Agriculture were handled and the adjustment of formulas for historical changes in livestock weight.

Undisclosed Data from the Census of Agriculture

The estimation of nutrients from manure relies on knowing the number of animals in each county in each livestock category: cows, hogs, poultry, sheep, and horses. These numbers are taken from the 5-year Census of Agriculture and include data that may be withheld by the USDA for privacy purposes. Withholding may occur with data for livestock, crops, or other commodities. The number of counties that have withheld data for any specific commodity varies considerably but has increased in more recent years following a trend of smaller family farms being replaced by larger farms. As a typical example for data on hogs from the 3,066 counties used here—26 counties had withheld data in 1974, 212 counties had withheld data in 1992, and 576 counties had withheld data in 2012. The Census of Agriculture releases the data for these counties marked with a special code “D” to distinguish them from counties that have none of that commodity. For some counties, the withheld value is likely to be large—for example, a county with a single very large livestock facility. For the methods described in this report, estimating and filling in the withheld values was preferable to leaving them blank. Previous USGS publications had methods that differed by animal type as to whether and how the withheld data were estimated. Withheld data for poultry, sheep, or horses were not filled in previous publications. The goal here is to provide a consistent method by which to make estimates based on withheld data for all animal types.

One method to estimate the withheld data would be to apportion the State sum of the commodity not already accounted for to the withheld counties. Unfortunately, State sums are sometimes also withheld. For example, the State sum for Arizona hogs was withheld for the years 2002, 2007, and 2012; for Maryland, 2002 and 2007; for Nevada, 2002 and 2012; and so on. These data withholdings make estimating data based on State sums much more difficult.

The approach taken here, also described in Falcone and LaMotte (2016), is to simply fill in the data for the most recent year for which there are data for that county. For example, if data were withheld for the year 2007 for a county but not in 2002, the value for 2002 was used; if data for 2002 were not available, then the data for the next year (1997) were checked, and so on, going back six time periods (30 years). If there were undisclosed data for more than six time periods, then the entries were left blank. This was an uncommon occurrence: for example, for hogs in 2017, data entries for 14 of 515 counties with withheld data were left blank in this report; in 1992, data for hogs in 2 of 212 counties were left blank; and in 1974, data for hogs in none of 26 withheld counties were left blank. During the earliest time periods, the checks were done going forward in time; withheld data were quite uncommon in the 1950s and 1960s.

The result of this approach was that data in this report were estimated for more counties than in previous USGS publications. The USGS data release associated with this report (Falcone, 2021) provides tables by animal type showing which counties were estimated.

Adjusting Data for Changes in Livestock Weight

Manure and consequently nutrient production, as well as potential other characteristics (for example, dairy-cow milk production; Nennich and others, 2005), are related to animal weight (Puckett and others, 1998; Yang and others, 2016). Livestock weight has increased substantially over time in the United States because of genetic evolution and improvements in feeding. For example, in 1960, the average weight per animal of federally inspected live cattle was 1,033 pounds; in 2017, the average was 1,351 pounds (U.S. Department of Agriculture, 2020b). For hogs, the average weight increased from 239 to 283 pounds; for broiler chickens, the average weight increased from 3.4 pounds to 6.4 pounds. Previous USGS manure estimations of nutrients relied on formulas based on animal-weight data for 1992 (Puckett and others, 1998; Ruddy and others, 2006). Because this report covers a longer time range than previous USGS publications, this project adopted the method used by Yang and others (2016): 1992 was chosen as the base year, and then nutrient-production formulas were multiplied by a weighting coefficient based on the average animal weight during the target year, the year to be calculated. The weighting coefficient was calculated by dividing the average animal weight in the target year by the average animal weight in 1992. For example, the average weight for one sheep in 1964 was 98.92 pounds; in 1992, it was 126.50 pounds; and in 2017, it was 136.33 pounds (U.S. Department of Agriculture, 2020b). The nutrient formula used for sheep (Gronberg and Arnold, 2017) was therefore multiplied by the coefficient 0.782 for 1964 (98.92/126.50) and 1.078 for 2017 (136.33/126.50). The result was that nutrient-production data in this report for the years prior to 1992 will be somewhat lower than those listed in previous USGS publications; for years after 1992, the data will be somewhat higher, not accounting for any adjustments made to withheld data, as described previously.

Table 4. Tables retrieved from LaMotte (2015) for 1950–2012 manure calculations.

LaMotte (2015) table	LaMotte (2015) description	Gronberg and Arnold (2017) equivalent livestock type
bcows.txt	Beef cows inventory	Beef cows
mcows.txt	Milk cows inventory	Milk cows
cows.txt	All cattle and calves inventory	Other cows (all cattle minus [beef + milk])
hogs.txt	Hogs and pigs inventory	Hogs and pigs
broilers.txt[1]	Broiler chickens inventory	Broilers and pullets
chickens.txt	Chickens (layers) inventory	Layers
turkeys2500.txt[2]	Turkeys inventory	Turkeys
sheep.txt	Sheep and lambs inventory	Sheep and lambs
horses.txt	Horses and ponies inventory	Horses and ponies

[1]For broilers, 1950–64 inventory data were not reported; however, sales data were reported. Based on averages for other years, inventory was estimated as equal to 0.28 of sales.

[2]For turkeys, turkeys2500.txt data for 1969 and 1974 are from economic class 1–5 farms (the classes of largest farms).

Method for Producing County-Level Nutrient Estimates from Livestock Manure for 1950–2017

County data for each of the pertinent livestock types for 1950 through 2012 were retrieved from LaMotte (2015). Table 4 lists the tables retrieved from LaMotte (2015) and the corresponding animal type to which they mapped in Gronberg and Arnold (2017). For most animal types, LaMotte reported both “inventory” (number of animals on hand at time of census) and “sales” (total number sold in year). The statistic that matched Gronberg and Arnold (2017) and previous USGS efforts was “inventory,” which has been used here.

Corresponding numbers of animals for 2017 were retrieved from the USDA Quick Stats tool (U.S. Department of Agriculture, 2020a). Care was taken that the values corresponded to the LaMotte data by retrieving 2012 data as well and ensuring that values matched what was given in LaMotte for 2012. The values for all years were checked for withheld data codes and adjusted as described above.

The nutrient output was calculated by multiplying the number of animals by the formulas given in Gronberg and Arnold (2017) and the animal-weight coefficient as described above (table 5). Because data for horses were not available from the USDA, horse weights were considered to be static over time.

Table 5. Weighting coefficients based on changes of average animal weight from 1992.

[coef, coefficient. Animal weights from U.S. Department of Agriculture (2020b), based on federally inspected averages of live-slaughter weights in pounds]

Year	Cattle coef	Hogs coef	Sheep coef	Broilers coef	Chickens coef	Turkeys coef
2017	1.152	1.117	1.078	1.374	1.295	1.425
2012	1.113	1.087	1.164	1.297	1.175	1.376
2007	1.088	1.064	1.089	1.221	1.270	1.307
2002	1.069	1.049	1.068	1.133	1.134	1.233
1997	1.003	1.013	1.064	1.066	1.063	1.104
1992	1.000	1.000	1.000	1.000	1.000	1.000
1987	0.946	0.980	0.945	0.950	0.952	0.937
1982	[1]0.943	[1]0.974	[1]0.930	0.895	0.944	0.890
1978	[2]0.879	[2]0.942	[2]0.862	0.861	0.915	0.869
1974	0.899	0.969	0.831	0.840	0.935	0.837
1969	0.878	0.948	0.821	0.797	0.981	0.821
1964	0.889	0.962	0.782	0.770	1.016	0.748
1959	0.892	0.948	0.783	[3]0.744	[3]1.040	[3]0.693
1954	[4]0.869	[4]0.942	[4]0.780	[3]0.744	[3]1.040	[3]0.693
1950	[4]0.869	[4]0.942	[4]0.780	[3]0.744	[3]1.040	[3]0.693

[1]For 1982, the cattle, hogs, and sheep data are from 1986, the year closest in time which had these data.

[2]For 1978, the cattle, hogs, and sheep data are from 1976, the year closest in time which had these data.

[3]For 1959, 1954, and 1950, the poultry data are from 1960, the year closest in time which had these data.

[4]For 1954 and 1950, the cattle, hogs, and sheep data are from 1958, the year closest in time which had these data.

Regional and National Results

Figure 2 shows the mass of nutrients from farm-fertilizer nutrients for all years in the conterminous United States. Because the Alexander and Smith (1990) data do not differentiate between farm and nonfarm nutrients applied from 1950 through 1982, the proportion of farm-fertilizer nutrients was estimated by multiplying the total by 0.98 (Brakebill and Gronberg, 2017). Figure 3 shows the mass of nutrients from nonfarm fertilizer (note the difference in the range of *y*-axis numbers from figure 2: nonfarm nutrients have much lower numbers). As in figure 2, because the Alexander and Smith (1990) data do not distinguish farm from nonfarm nutrients, the proportion of nonfarm-fertilizer nutrients for 1950 through 1982 has been estimated by multiplying the total by 0.02. Figure 4 shows the mass of nutrients from manure.

Figures 5, 6, 7, and 8 show mapped changes of nitrogen from fertilizer, phosphorus from fertilizer, nitrogen from manure, and phosphorus from manure, respectively, by county, in units of kilograms per square kilometer. All figures were scaled to the same breakpoints. Fertilizer includes both farm and nonfarm inputs. Maps were created by dividing the sum of the nutrient mass by the total county area. The most significant changes in nutrients from fertilizer were increases in nitrogen input in the Midwest and lower Mississippi regions. The most significant changes in nutrients from manure were caused by an intensification or centralization of nutrients in a smaller number of geographic locations—for example, in Iowa and North Carolina. These changes follow a general trend of small livestock farms being replaced by large industrial facilities (Falcone and others, 2019).

Masses of Nutrients from Manure in this Study Compared to Previous USGS Studies

For this report, masses of nitrogen and phosphorus from manure were calculated for all years, even for those years for which data had been previously published in USGS reports (1982–2012). The differences between results described in this report and those previously published were small at the national scale (fig. 9). As noted above, the two differences were that (a) more counties that had withheld data were estimated in the current report and (b) manure coefficients were adjusted for changing animal weights over time, with a baseline date of 1992. For years prior to 1992, estimates from this report thus tend to be slightly lower than previously published estimates, whereas estimates made for years after 1992 are higher. The difference is lowest for the year 1992. The 1992 results differ from previously published estimates only because more withheld data were estimated through the use of the current method.

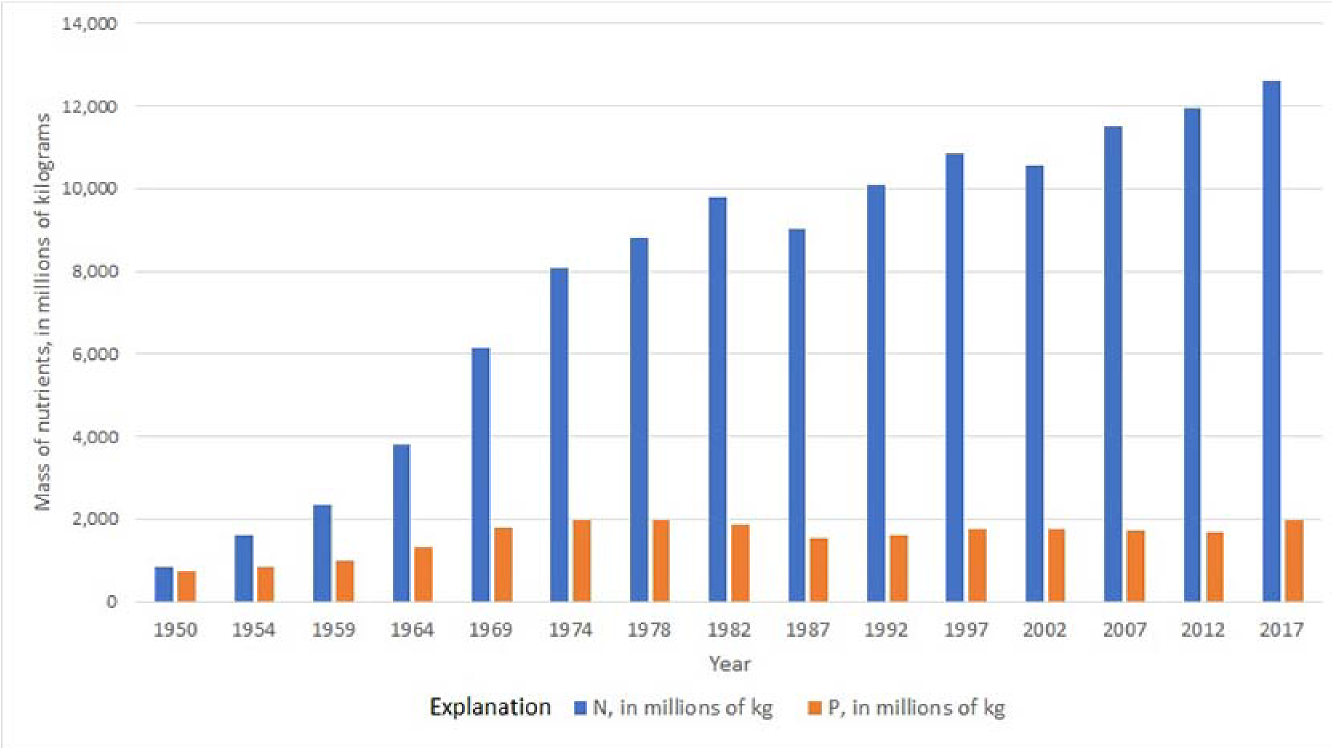

Figure 2. Bar chart showing the mass of nutrients from farm fertilizer by year in the conterminous United States. kg, kilograms; N, nitrogen; P, phosphorus.

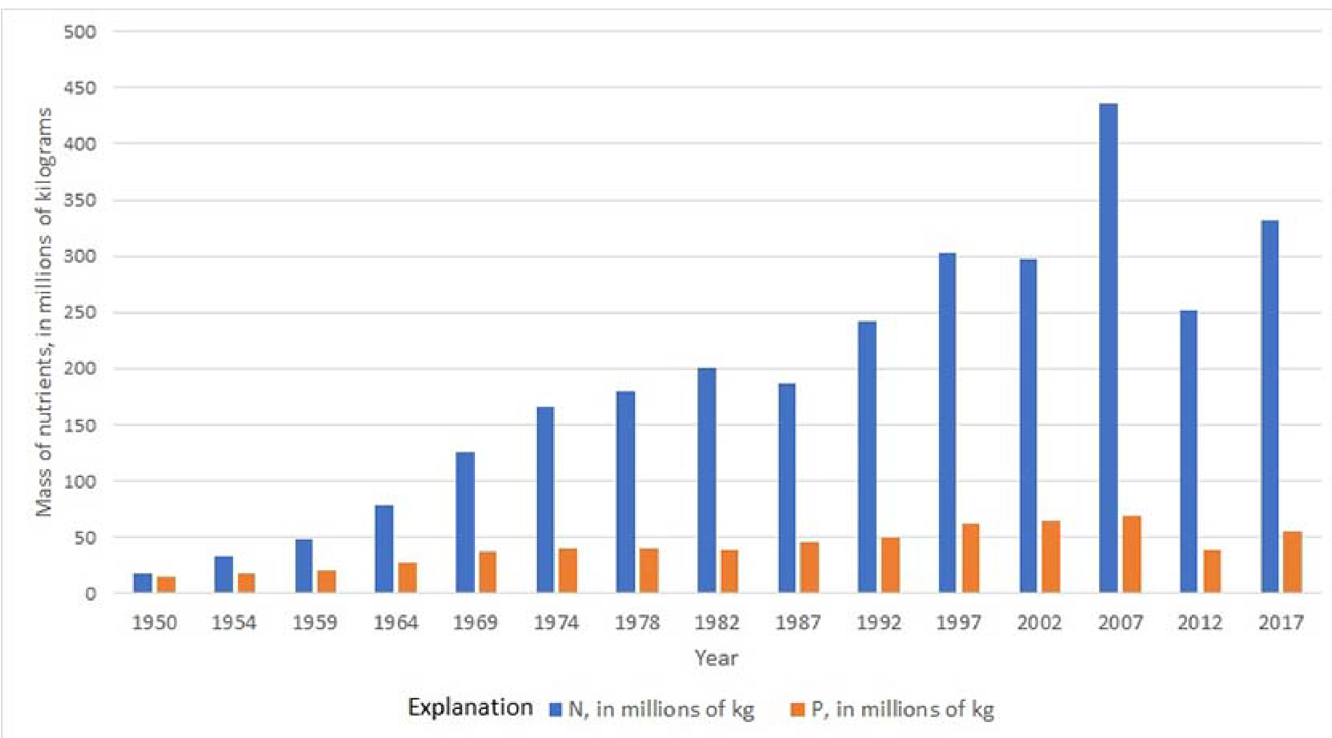

Figure 3. Bar chart showing the mass of nutrients from nonfarm fertilizer by year in the conterminous United States. kg, kilograms; N, nitrogen; P, phosphorus.

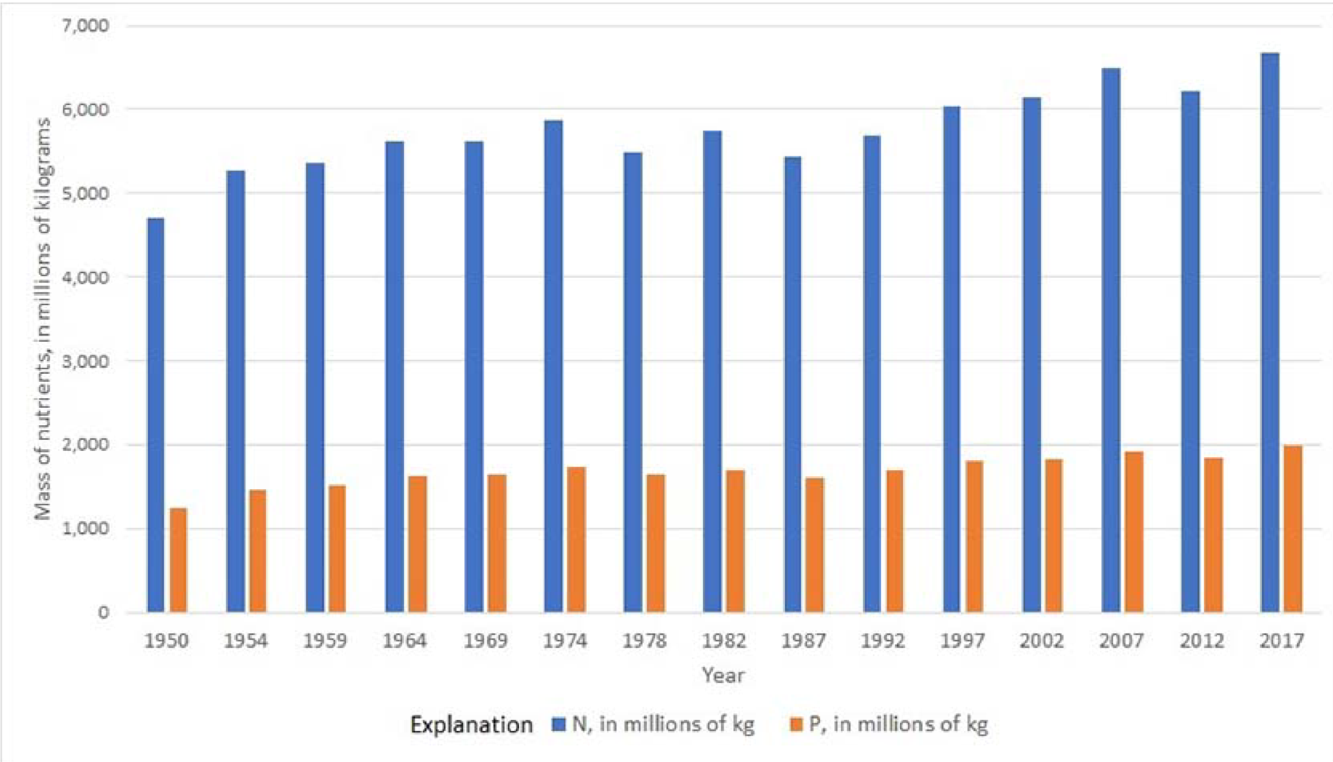

Figure 4. Bar chart showing the mass of nutrients from manure by year in the conterminous United States. kg, kilograms; N, nitrogen; P, phosphorus.

Comparison to Non-USGS Data

Farm Fertilizer 2017

One independent source of nutrient estimates for 2017 farm-fertilizer use may be derived from USDA Economic Research Service (ERS) State-level data tables (U.S. Department of Agriculture, 2019, file “fertilizeruse.xls”). For most agricultural States, annual estimates of application rates of nitrogen, phosphate, and potash in units of pounds per fertilized acre are given, as well as an estimate of the percentage of acres that are fertilized, for four major crops: corn, cotton, soybeans, and wheat. It is also possible to determine the acreage of each of those four crops by State from the USDA National Agricultural Statistics Service Cropland Data Layer (CDL; U.S. Department of Agriculture, 2020c), a 30-meter national-cropland raster product. It is thus possible to estimate the masses of nitrogen and phosphorus from fertilizer for those four crops by State. These were the steps taken to do this:

a. Calculate the number of acres by State of corn, cotton, soybeans, and wheat from the 2017 CDL.

b. Using the ERS data for the year 2017, multiply the application rate per acre by the number of acres and by the percentage of acres that are fertilized. For example, if the application rate of nitrogen fertilizer for corn in a State is 140 pounds per fertilized acre, and there are 1 million acres of corn and 96 percent of corn acres are fertilized, the mass of nitrogen would be (140 × 0.96 × 1 million) = 134,400,000 pounds, or 60,963,000 kilograms of nitrogen from fertilizer applied to corn. This calculation was done for the 19 States for which there were 2017 application-rate data available from the ERS. For States that did not have ERS estimates for 2017, the average of the estimates for 2016 and 2018 was used.

c. The ERS does not provide nutrient-application rates or numbers of fertilized acres for crops other than corn, cotton, soybeans, and wheat. Therefore, an estimate was made based on average values for the four major crops. This estimate was done by calculating the total area for all other crops from the CDL by State, then multiplying that value by the average fertilizer-application rate and the average percentage of fertilized acres for each of the four major crops for that State.

d. ERS estimates for application rates and fertilized acres are given for phosphate, P_2O_5; however, the desired calculation for this report was for phosphorus. For this reason, the mass of phosphate (P_2O_5), which resulted from the above calculations, was multiplied by 0.437 to convert it to the mass of phosphorus (Flynn, 2014).

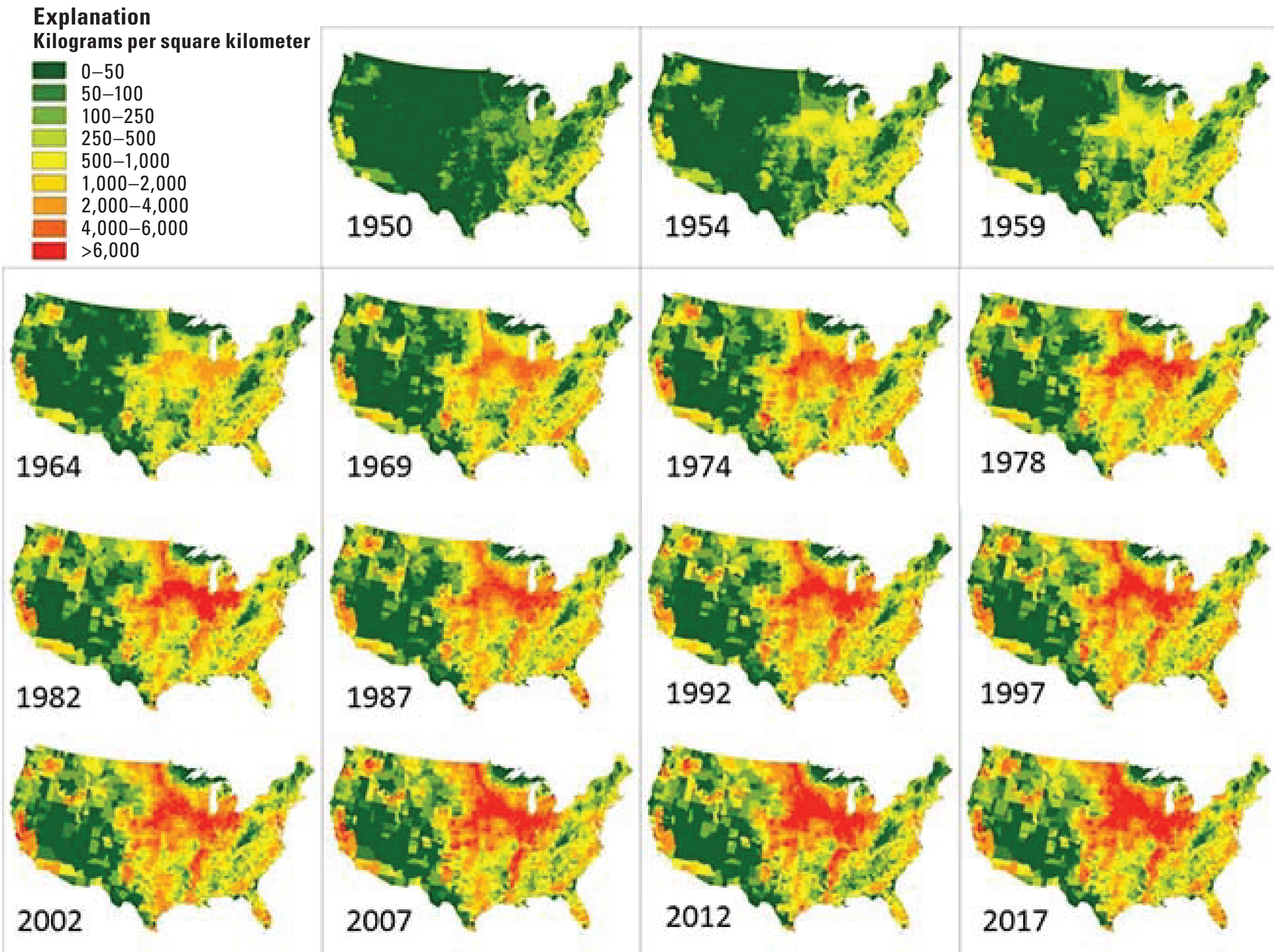

Figure 5. Spatial distribution of mass of nitrogen from fertilizer in the United States, 1950–2017.

e. Sum the masses of nitrogen and phosphorus for each State, and compare each of these sums to the sums of the masses of nitrogen and phosphorus by State from the current report (fig. 10).

Manure

Yang and others (2016) estimated county-level nutrients from manure for 5-year periods from 1930 through 2012 by using a method similar to that described here. National-scale data were publicly available (Yang and others (2016), supplementary fig. S6) and compared to the data published here for nitrogen from manure (fig. 11). Estimates from the two reports are similar for the years 1950 through 1987, although the Yang and others (2016) report has slightly higher estimates for the years thereafter.

A second comparison was made to State-level estimates of nitrogen mass that were available for the year 2007 from the U.S. Environmental Protection Agency (U.S. Environmental Protection Agency, 2020) (fig. 12). The two reports show similar results.

Benefits and Possible Improvements

The major benefit of these data is to provide estimates spanning nearly 70 years for nutrients from fertilizer and manure at a reasonably detailed scale for the conterminous United States. The improvements described below may be considered for future versions of this report.

Using AAPFCO data

For fertilizer, previous USGS publications were derived from AAPFCO data as noted above. Because these data were not available for 2017, a different method was used, although one similar in nature to other efforts (Stewart and others, 2019). When 2017 AAPFCO fertilizer data become available, it may be worthwhile to evaluate the effort needed to generate new 2017 nutrient estimates from those data.

Dairy-cow milk production

This report accounted for changing animal weights over time; however, it may be worthwhile to implement further adjustments based on dairy-cow milk production. Nennich and

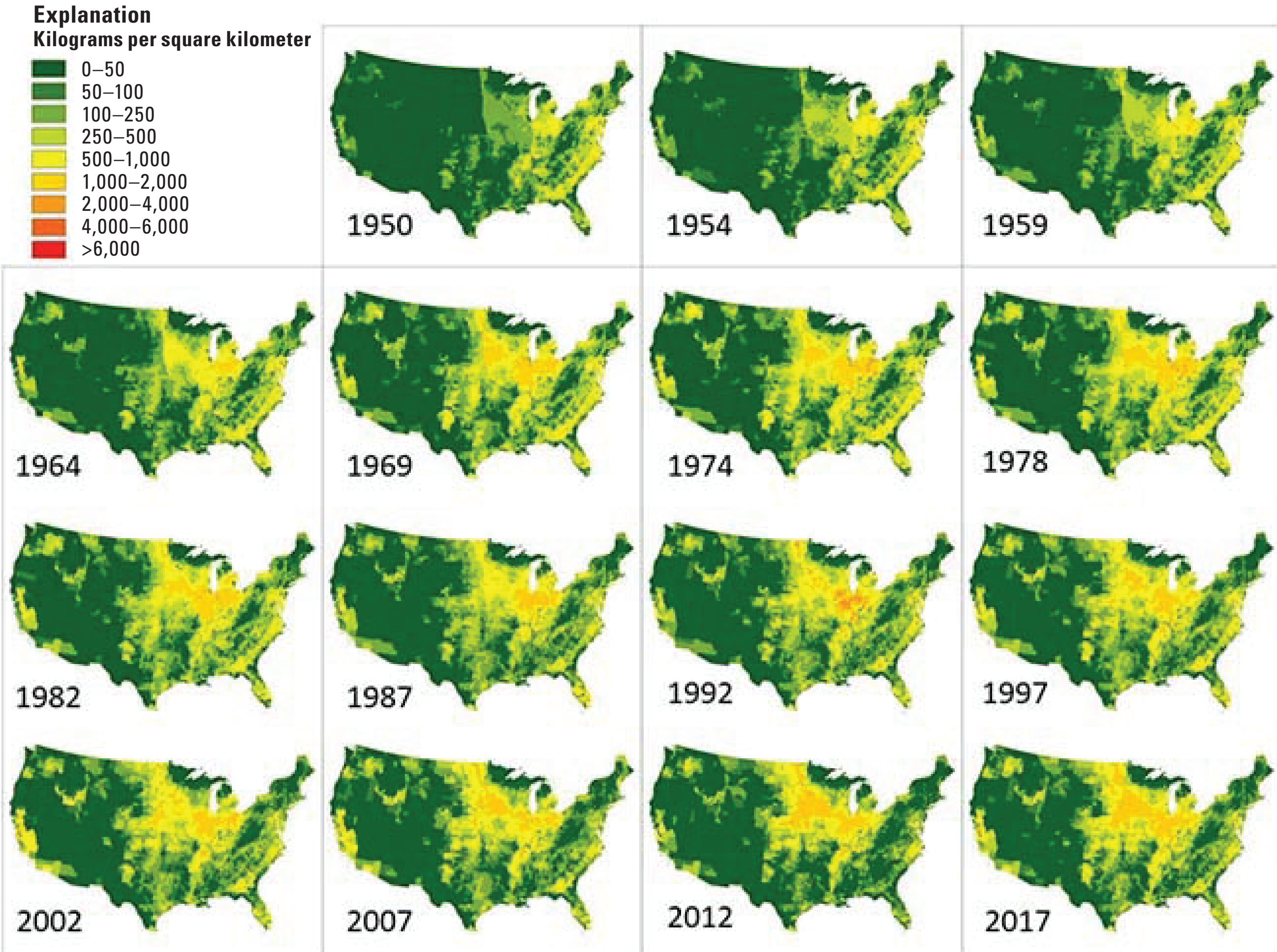

Figure 6. Spatial distribution of mass of phosphorus from fertilizer in the United States, 1950–2017.

others (2005) indicate that changes in milk production, which is even more pronounced than animal-weight changes over time, may be a better measure for estimating nutrient production for that subclass of animals.

County-boundary changes

Except for 2017, the source agricultural data used here were taken from the database given by LaMotte (2015), which had mostly normalized data to account for boundary changes and minor merges of cities into counties (primarily in Virginia). Several small boundary changes were not accounted for. One example was Broomfield County, Colorado, which was created in 2001 from parts of four surrounding counties (Adams, Boulder, Jefferson, and Weld). Broomfield is, however, a small and largely urban county, and thus not likely to contribute as much nutrient mass as agricultural counties. For example, in 2012, Broomfield had an inventory of nine cows—the primary livestock in Colorado—compared to the total of 138,313 cows in the other 4 counties (U.S. Department of Agriculture, 2020a). For that reason, Broomfield County was omitted from this dataset. It would be feasible (with considerable effort) to normalize the data for these counties over time; however, because these differences were insignificant, doing so was deemed to be beyond the scope of this study.

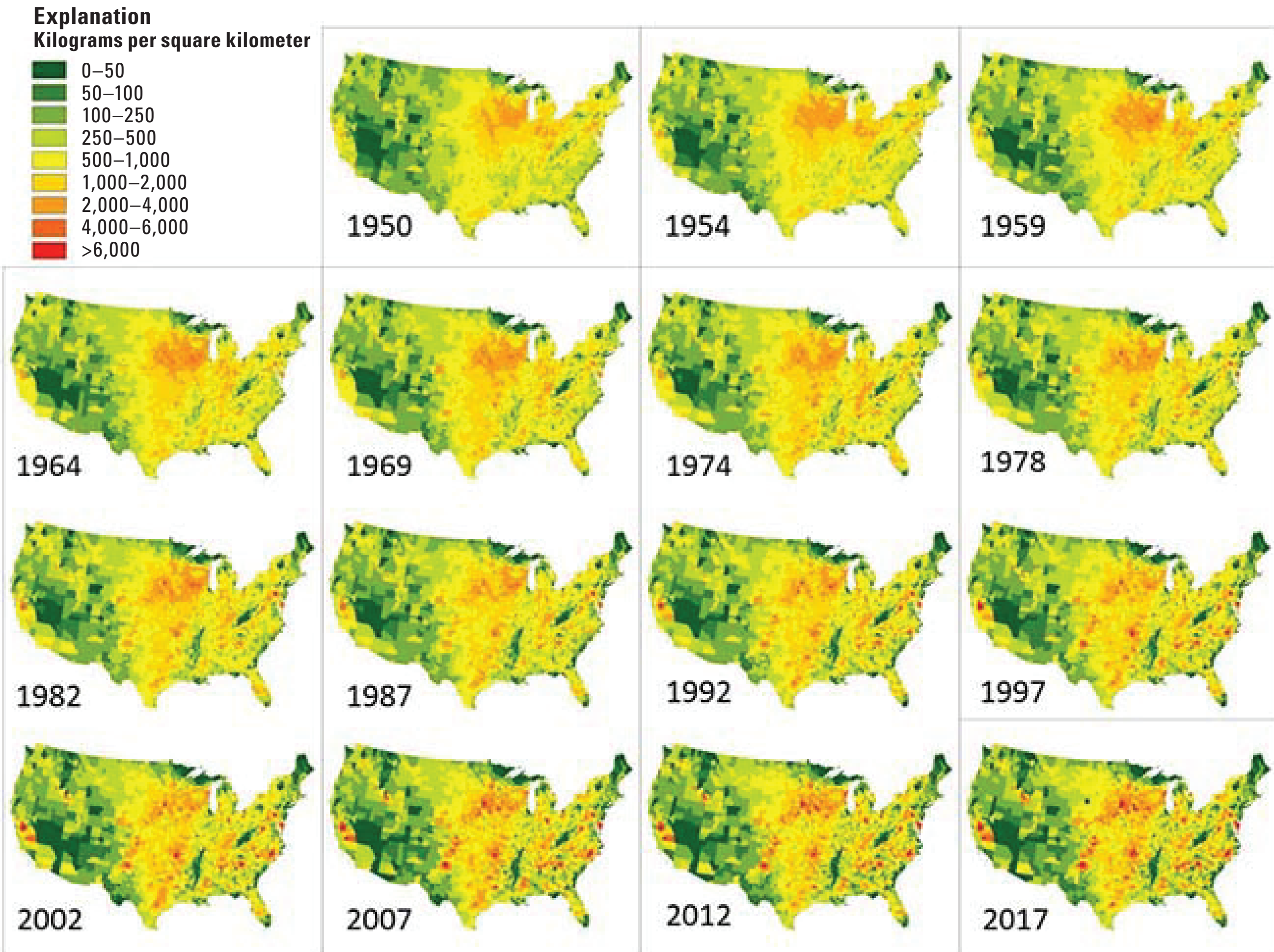

Figure 7. Spatial distribution of mass of nitrogen from manure in the United States, 1950–2017.

Summary

This report provides county-level estimates of nitrogen and phosphorus from both fertilizer and manure applied throughout the conterminous United States for the period 1950–2017 at approximately 5-year intervals. Fertilizer-based estimates of nutrients for the period 1950–2012 are provided as a convenience from republications of data from previous U.S. Geological Survey reports. Estimates of nutrients from fertilizer for 2017 are given as a new product generated from a random-forests regression model based primarily on 2017 crop, land-use, and fertilizer expenditure data. Estimates of nutrients from fertilizer for the period 1987–2017 are further broken out into farm and nonfarm usage. Estimates of nutrients from manure for all years are generated as new estimates calculated by methods similar to those employed in previous U.S. Geological Survey reports. The major differences in estimates of nutrients from manure between this report and previous publications were the methods for (a) handling withheld data and (b) accounting for historical changes in animal weight over time. For use as a time series, these data are best suited for use in multicounty or regional analysis.

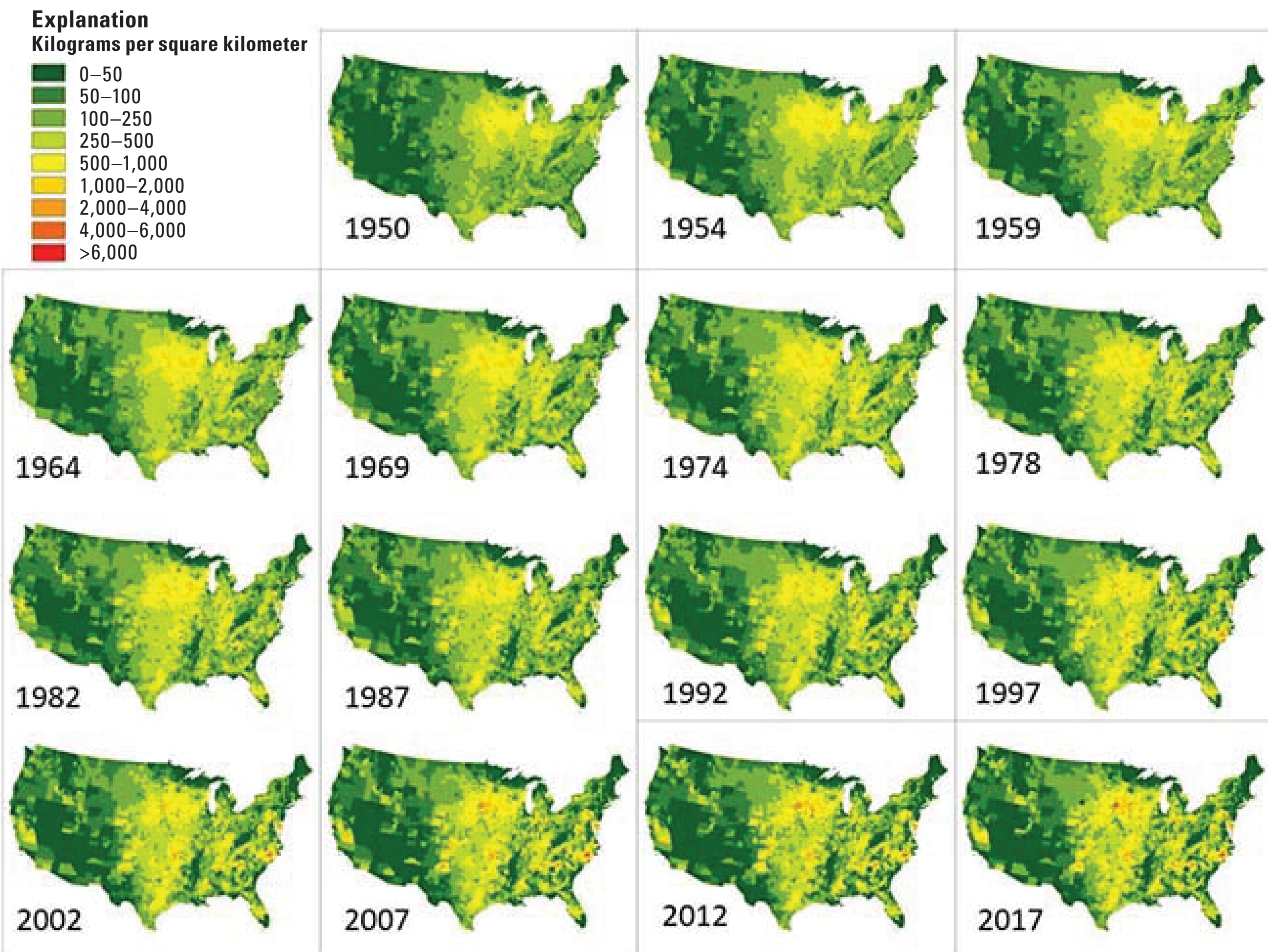

Figure 8. Spatial distribution of mass of phosphorus from manure in the United States, 1950–2017.

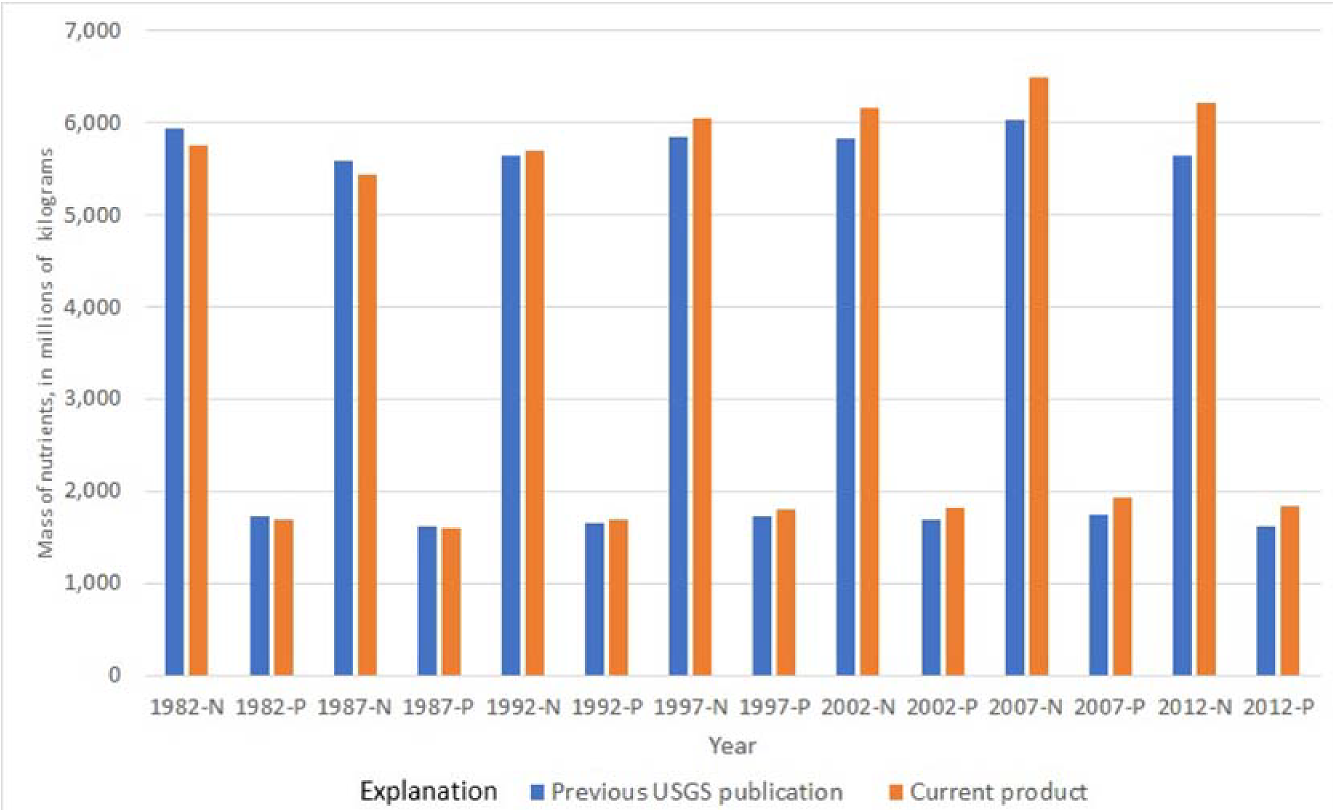

Figure 9. Bar chart comparison of N and P inputs given in this report for manure and in previous USGS reports (Ruddy and others, 2006; Mueller and Gronberg, 2013; and Gronberg and Arnold, 2017). N, nitrogen; P, phosphorus. Units in millions of kilograms.

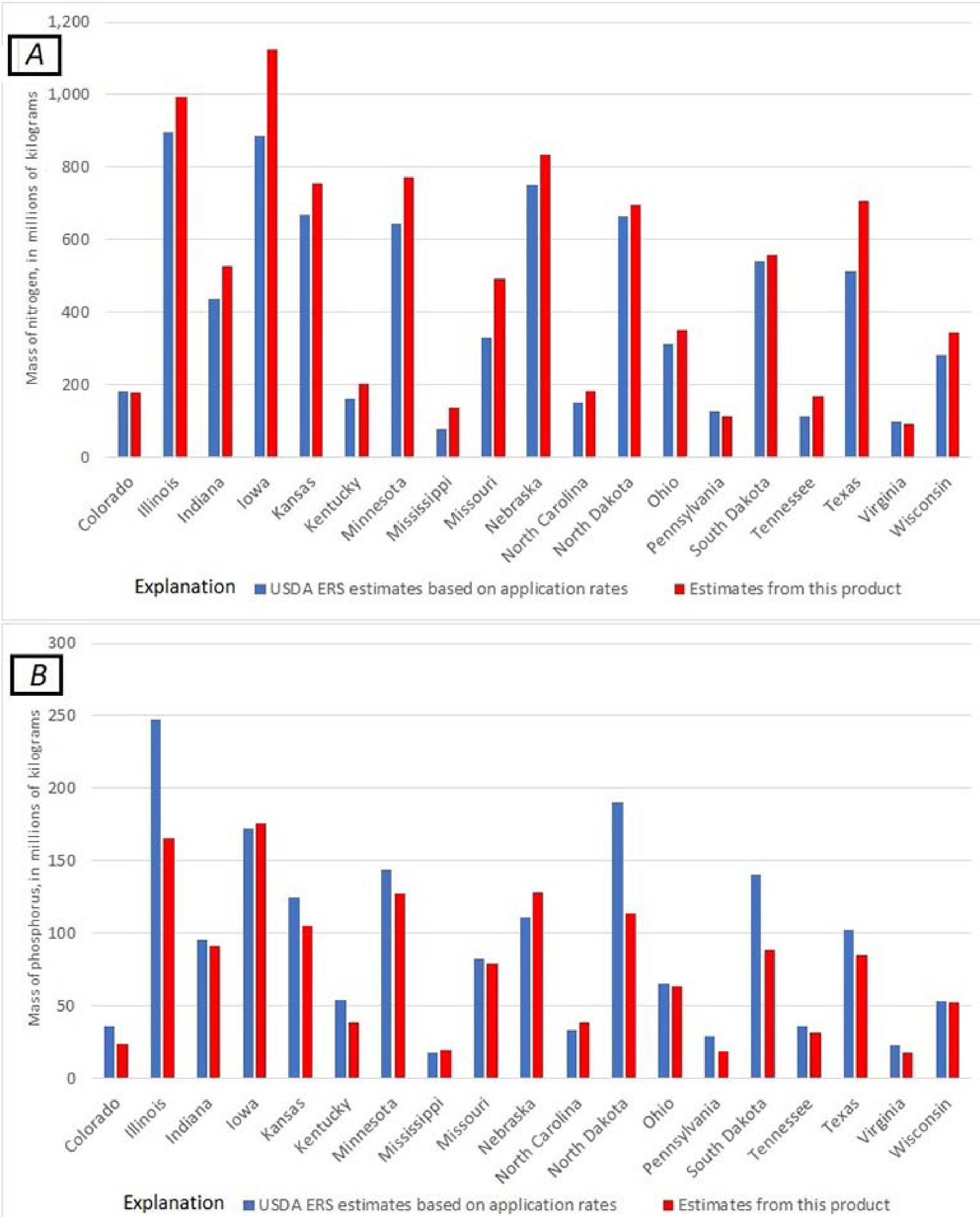

Figure 10. Bar chart comparison of statewide estimates of masses of *A*, nitrogen (N, top) and *B*, phosphorus (P, bottom) from farm fertilizer in 2017.

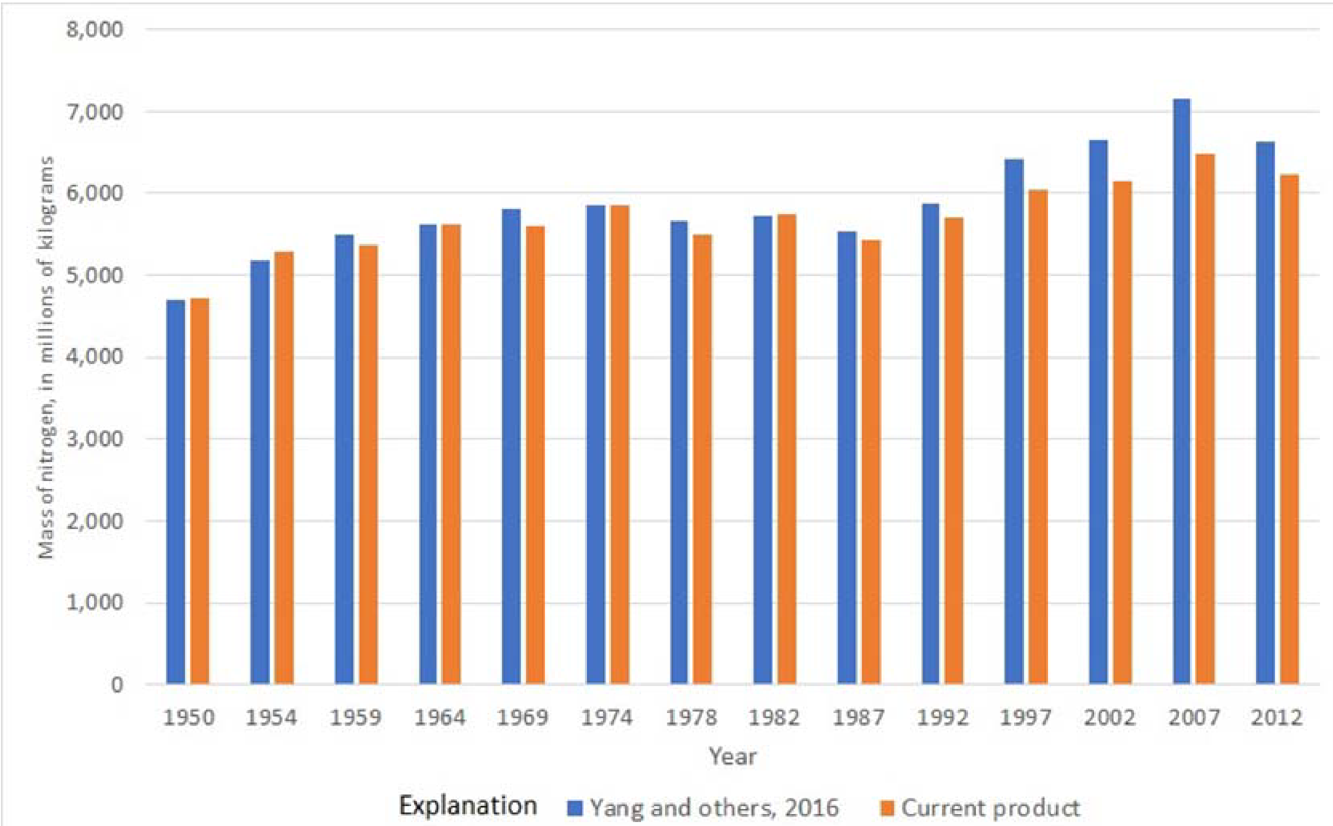

Figure 11. Bar chart comparison of masses of national-scale nitrogen from manure for 1950–2012 masses calculated by Yang and others (2016) for the same time period.

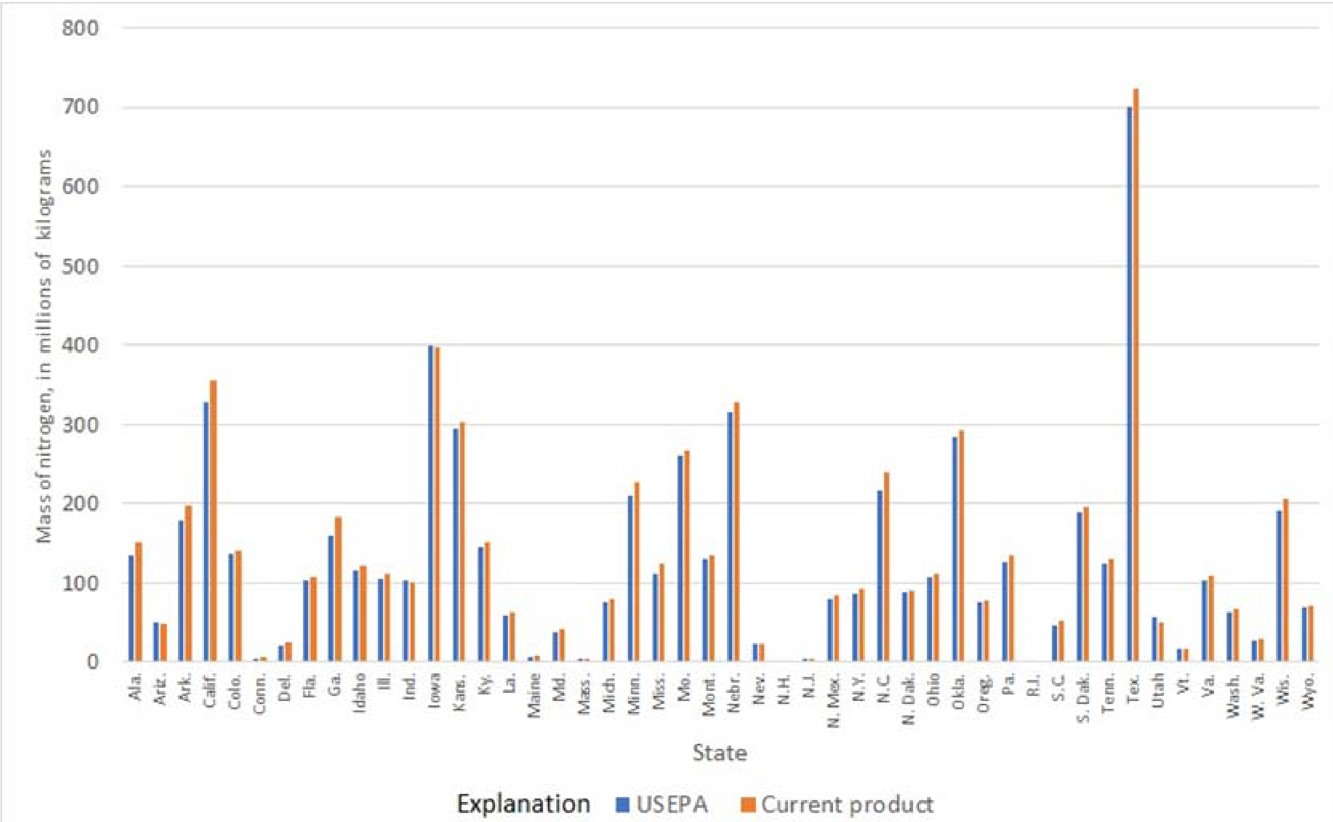

Figure 12. Bar chart comparison of State-level nitrogen mass from manure for 2007 between data given in this report and data from the U.S. Environmental Protection Agency (2020).

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