TREND-Nitrogen 2.0 Dataset and File Description

The TREND-Nitrogen 2.0 dataset provides county-scale nitrogen mass balance data for the contiguous U.S. for the period 1930-2017. TREND-N 2.0 is an updated and amended version of the original Trajectories Nutrient Dataset for Nitrogen (TREND-N) dataset made available through PANGAEA (doi.org/10.1594/PANGAEA.917583). For additional details and discussion regarding the original TREND-Nitrogen data, please refer to Byrnes et al. (2020a). If access to the original dataset is needed, please contact the authors. Correspondence should be directed to nandita.basu@uwaterloo.ca.

1.0 File Naming

There is one text file for each component of the nitrogen (N) mass balance. File names are provided in Table 1.

Table 1. TREND-Nitrogen 2.0 N mass balance components and associated text files for the dataset.

Nitrogen mass balance component	Dataset .txt files associated with component
N surplus	N_surplus.txt
Atmospheric N Deposition	Atmospheric_Oxidized.txt Atmospheric_Reduced.txt
Manure N	Lvst_SheepGoat.txt Lvst_Turkey.txt Lvst_Broilers.txt Lvst_LayersPullets.txt Lvst_DairyCow.txt Lvst_BeefCow.txt Lvst_OtherCattle.txt Lvst_Hogs.txt

	Lvst_Equine.txt
Biological N Fixation	Fix_Pasture.txt Fix_Cropland.txt
N Fertilizer	Fertilizer_NonAgriculture.txt Fertilizer_Agriculture.txt
Crop N Uptake	CropUptake_Pasture.txt CropUptake_Cropland.txt
N in Human Waste	Human.txt

1.0 File Structure

As described above, each data file represents one component of the N mass balance. Each row of the data file represents data for an individual U.S. county. Data columns are structured as follows:

Column 1: States FIPS Code (U.S. Federal Information Processing System)

Column 2: County FIPS Code (3 digits)

Column 3: U.S. County GEOID (5 digits)

Column 4: County Area (hectares)

Columns 5 - 92: Annual Data (1930-2017).

N mass balance data in columns 5-92 are all given in units of kg-N ha^{-1} y^{-1}.

2.0 County Boundaries

Counties areas and boundaries in the dataset correspond to boundaries in the 2017 county shapefile available on the U.S. Cartographic Boundary Files website: https://www.census.gov/geographies/mapping-files/time-series/geo/carto-boundary-file.2017.html. In cases where county boundaries have shifted over time, we have used reported census data for the historical county boundaries and then reaggregated the data to the 2017 county boundaries. County boundaries are projected in EPSG:5070 - NAD83 / Conus Albers.

3.0 Notes on N Mass Balance Data Methods

Methods for calculating county-scale N mass balance data are described in detail in Byrnes et al. (2020a). Details regarding changes in methodology for TREND-Nitrogen 2.0 are provided below.

3.1 Atmospheric Deposition

The dataset includes estimates of county-scale magnitudes of both reduced (NH_x) and oxidized (NO_x) forms of atmospheric N deposition and includes both wet and dry deposition.

For the period 1930-2014, county-scale deposition of reduced N forms was calculated by aggregating modeled grid-scale (250 km x 250 km) estimates of reduced wet and dry N deposition (Durack and Taylor 2019) to the county scale, and then summing the monthly values to obtain annual estimates. For the period 2015-2017, deposition magnitudes were assumed to remain constant.

Deposition of oxidized forms of N was calculated using the methods described in Byrnes et al. (2020a), with the modifications described herein. Monitored data for oxidized N Deposition was obtained from the National Atmospheric Deposition Program (NADP) (1987-2017). We next used a backcasting approach to estimate deposition for the period 1930-2016. For the backcasting, we used historical estimates of CO_2 emissions from fossil fuel combustion (Oak Ridge National Laboratory 2017) as a scaling factor. CO_2 emission trends were assumed to be a reasonable proxy for N deposition trends based on the strong correlation (R^2=0.98) between 1940-1986 N emission rates (Houlton et al. 2013) and reported CO_2 emissions.

3.2 Crop and Livestock Production

Methodology and data sources for the conversion of crop and livestock production to conversion to N values can be found in Byrnes et al. (2020b), with relevant updates described below.

3.2.1 Censored Data

In TREND-Nitrogen 1.0, U.S. Census of Agriculture livestock inventory values were obtained from the Haines et al. (2018). The Haines et al. (2018) dataset, however, did not differentiate between censored data (marked by a (D) in the census) and actual zero inventory values. To address this issue for TREND-Nitrogen 2.0, we now use, where available, livestock inventory values from Falcone (2021) for the period 1950 to 2017 . Pullets, mules and donkeys, and goat inventories were not available from Falcone (2021), and for these categories we continue to use the Haines et al. (2018).

3.2.2 Annual Values

In TREND-Nitrogen 1.0, we used U.S. Census of Agriculture data, which is administered every 5 years, to estimate annual N surplus and component values, and interpolated between these values to provide annual estimates. For the TREND-Nitrogen 2.0 dataset, we now use annual USDA National Agricultural Statistics Service (NASS) survey data to supplement the census data. Survey data is only compiled for major row crops and small grains as well as livestock categories used for economic or policy-relevant issues affecting the farm sector (Table 2). While data are collected and reported at the county scale, categories included vary from state to state. For more information, see the USDA NASS webpage (https://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Crops_Stocks/index.php). We incorporated USDA annual survey data for 20 crop and 7 livestock categories. To integrate the survey estimates with census data, the county survey data was scaled based on the mean ratio of a given county's census data to survey data over a 20-year window.

Table 2. Available crop and livestock categories in NASS survey data.

Annual data available for crops		
Alfalfa hay	Barley	Grain corn
Silage corn	Hay, excluding alfalfa	Oat
Potatoes	Rice	Rye
Soybeans	Wheat	Sugarbeets
Tobacco	Grain sorghum	Silage sorghum
Flaxseed	Beans	Cotton
Peanuts	Sugarcane	
Annual data available for livestock		
Beef cow	Milk cow	Other cattle*
Hogs	Sheep and lambs	Goat
Chickens, excluding broilers		

*calculated using "other cattle = total cattle - beef cow - milk cow"

3.2.2 Methodology for Gap-Filling Censored Data

In TREND-Nitrogen 2.0, gaps in the census record are filled for missing or censored data. Two different approaches are used for the gap-filling. For crops, we calculate the difference between reported state-level production values and the sum of all reported county-level values. This difference is then apportioned to all of the counties with censored data as a function of the ratio between the county-scale and state-scale values from the nearest census years. We use up to three of the closest past census years with available data to calculate the ratio.

For livestock, we have now adopted the approach described by Falcone (2021). If data are censored, we use the inventory value from the previous census year, going back as many as six census years, if necessary. If over this period of six census years the data is still undisclosed, we set the inventory to 0.

3.2.2 Methodology for Estimating Pasture N Uptake

In TREND-Nitrogen 2.0, we use estimates of the fraction of confined cattle as a tool to better our estimates of pastureland N uptake. To calculate the estimated fraction of cattle available to graze on pastureland, we use state-specific cattle confinement factors (Kellogg et al. 2000). Using this methodology, we developed county-scale confinement factors for all three census cattle categories (milk cows, beef cows, and other cattle).

To aggregate the confinement factors from Kellogg (2000) to the census categories, we used cattle inventories from the NANI Toolbox by Hong et al. (2012). The table with the state-specific confinement factors is provided below (Table 3).

Table 3. State-level confinement factors for beef cows, milk cows, and other cattle. The confinement factor refers to the fraction of each indicated livestock category that does not have access to pasture.

State	Beef Cow	Milk Cow	Other Cattle	State	Beef Cow	Milk Cow	Other Cattle
AL	0.00	0.40	0.02	NE	0.08	0.80	0.63
AZ	0.05	0.80	0.52	NV	0.05	0.80	0.26
AR	0.10	0.50	0.24	NH	0.10	0.80	0.34
CA	0.05	0.80	0.43	NJ	0.10	0.80	0.35
CO	0.05	0.80	0.59	NM	0.00	0.85	0.31
CT	0.10	0.90	0.42	NY	0.10	0.80	0.39
DE	0.10	0.80	0.39	NC	0.00	0.59	0.00
FL	0.00	0.50	0.05	ND	0.00	0.80	0.22
GA	0.00	0.70	0.10	OH	0.10	0.90	0.45
ID	0.00	0.95	0.42	OK	0.00	0.65	0.32
IL	0.10	0.80	0.38	OR	0.05	0.60	0.28
IN	0.10	0.60	0.33	PA	0.05	0.80	0.39
IA	0.10	0.87	0.46	RI	0.10	0.80	0.29
KS	0.05	0.85	0.48	SC	0.00	0.59	0.17
KY	0.08	0.70	0.30	SD	0.10	0.80	0.34
LA	0.00	0.50	0.03	TN	0.10	0.60	0.23
ME	0.10	0.80	0.37	TX	0.05	0.75	0.34
MD	0.10	0.80	0.37	UT	0.05	0.80	0.31
MA	0.10	0.80	0.35	VT	0.20	0.90	0.48
MI	0.08	0.90	0.50	VA	0.10	0.60	0.34
MN	0.15	0.90	0.58	WA	0.05	0.80	0.44
MS	0.10	0.60	0.23	WV	0.00	0.80	0.25
MO	0.10	0.65	0.30	WI	0.08	0.90	0.45
MT	0.01	0.75	0.22	WY	0.05	0.80	0.28

3.2.3 Crop Uptake Parameters

Updated parameter values for crop N uptake remain largely unchanged, except for the updated values shown in Table 4. Please refer to the supplemental information in Byrnes et al. (2020a) for all other parameters values.

Table 4. Corrected parameters for crop N uptake

Type	Reporting Unit	Unit conversion (kg/reporting unit)	N content (kg-N/kg)
Potatoes	Acres	18688	0.004
Sorghum, Silage	Green tons	526.17	0.013
Sorghum, Silage	Tons	907.18	0.013

3.2.3 Livestock Parameters

TREND-Nitrogen 1.0 relied on parameter values for livestock N excretion available from Hong et al. (2011). In TREND-Nitrogen 2.0, we now use parameter values obtained from the *Agricultural Waste Management Field Handbook* (USDA NRCS 2008) and have also introduced time-varying parameters to provide better consistency with estimates of county-scale manure N provided by Falcone (2021). Parameter values are assumed to represent the average manure N content for each livestock category in 2008. To estimate cattle N consumption, we use the ratio of cattle N consumption to cattle N excretion from Byrnes et al.(2020b) to scale the new excretion values (see Table 5).

Table 5. Livestock consumption (cattle) and excretion parameters (kg-N head^{-1} yr^{-1}) for 2008.

Livestock type	Animal N Intake (kg- N/animal/yr)	N in animal excretion (kg- N/animal/yr)
Cow, Beef	79.33	69.54
Cow, Milk	195.62	151.73
Cattle, Other (Heifer, Bull, Steers, Calves)	70.32	61.64
Goat		7.45
Sheep and lambs		7.45
Hog and Pigs		13.8
Horse		44.7
Poultry, Turkey		1.24
Poultry, Broiler		0.41
Poultry, Other Chickens		0.58

The past century has seen a change in the size of livestock due to selective breeding and changes in feed. To adjust our estimates of manure N production as a function of changing livestock mass over the past century, we use the approach developed by (Falcone 2021). Using annual surveyed slaughtered livestock weights (USDA ERS 2022), we calculated time-varying weight ratios of each given year's weights to the 2008 weights, and then used these ratios to scale the conversion values (see Table 6). Note that weights were not available for horses, and thus we assumed that horse size did not vary temporally.

Table 6. Weight of livestock normalized to 2008 weights. These values are used to scale the parameter values to adjust for changing livestock weight over time.

Year	Beef Cows	Milk Cows	Other Cattle	Hog	Sheep	Broiler	Other Chickens	Turkey	Goat	Horses
1930	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1931	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1932	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1933	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1934	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1935	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1936	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1937	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1938	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1939	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1940	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1941	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1942	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1943	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1944	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1945	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1946	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1947	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1948	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1949	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1950	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1951	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1952	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1953	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1954	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1955	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1956	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1957	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1958	0.79	0.79	0.79	0.89	0.71	0.60	0.85	0.52	0.71	1.00
1959	0.81	0.81	0.81	0.89	0.72	0.60	0.85	0.52	0.72	1.00
1960	0.80	0.80	0.80	0.89	0.72	0.60	0.85	0.52	0.72	1.00
1961	0.81	0.81	0.81	0.90	0.71	0.62	0.85	0.54	0.71	1.00
1962	0.80	0.80	0.80	0.90	0.71	0.61	0.84	0.55	0.71	1.00
1963	0.82	0.82	0.82	0.90	0.71	0.62	0.83	0.56	0.71	1.00
1964	0.81	0.81	0.81	0.91	0.72	0.62	0.83	0.56	0.72	1.00
1965	0.79	0.79	0.79	0.90	0.73	0.63	0.82	0.57	0.73	1.00
1966	0.80	0.80	0.80	0.91	0.74	0.63	0.81	0.57	0.74	1.00
1967	0.81	0.81	0.81	0.90	0.73	0.64	0.80	0.59	0.73	1.00
1968	0.80	0.80	0.80	0.90	0.74	0.64	0.80	0.61	0.74	1.00
1969	0.80	0.80	0.80	0.89	0.75	0.65	0.80	0.62	0.75	1.00
1970	0.82	0.82	0.82	0.90	0.76	0.65	0.80	0.62	0.76	1.00
1971	0.81	0.81	0.81	0.89	0.75	0.66	0.78	0.62	0.75	1.00
1972	0.82	0.82	0.82	0.89	0.76	0.67	0.77	0.63	0.76	1.00
1973	0.82	0.82	0.82	0.90	0.78	0.67	0.76	0.62	0.78	1.00
1974	0.82	0.82	0.82	0.91	0.76	0.68	0.76	0.63	0.76	1.00
1975	0.79	0.79	0.79	0.90	0.76	0.67	0.74	0.61	0.76	1.00
1976	0.80	0.80	0.80	0.89	0.79	0.68	0.76	0.63	0.79	1.00
1977	0.81	0.81	0.81	0.89	0.79	0.69	0.74	0.64	0.79	1.00
1978	0.81	0.81	0.81	0.89	0.80	0.70	0.75	0.65	0.80	1.00
1979	0.82	0.82	0.82	0.90	0.81	0.71	0.77	0.65	0.81	1.00
1980	0.83	0.83	0.83	0.90	0.81	0.71	0.76	0.64	0.81	1.00
1981	0.83	0.83	0.83	0.90	0.82	0.72	0.78	0.66	0.82	1.00
1982	0.84	0.84	0.84	0.91	0.83	0.72	0.77	0.67	0.83	1.00
1983	0.84	0.84	0.84	0.91	0.83	0.73	0.78	0.68	0.83	1.00
1984	0.85	0.85	0.85	0.91	0.84	0.75	0.77	0.69	0.84	1.00
1985	0.86	0.86	0.86	0.92	0.84	0.75	0.79	0.69	0.84	1.00
1986	0.86	0.86	0.86	0.92	0.85	0.76	0.78	0.69	0.85	1.00
1987	0.86	0.86	0.86	0.92	0.86	0.77	0.78	0.70	0.86	1.00
1988	0.88	0.88	0.88	0.93	0.90	0.77	0.79	0.72	0.90	1.00
1989	0.89	0.89	0.89	0.93	0.90	0.78	0.82	0.72	0.90	1.00
1990	0.89	0.89	0.89	0.93	0.91	0.78	0.81	0.73	0.91	1.00
1991	0.91	0.91	0.91	0.94	0.91	0.79	0.82	0.73	0.91	1.00
1992	0.91	0.91	0.91	0.94	0.91	0.81	0.82	0.75	0.91	1.00
1993	0.91	0.91	0.91	0.95	0.93	0.82	0.82	0.77	0.93	1.00
1994	0.93	0.93	0.93	0.95	0.91	0.83	0.86	0.78	0.91	1.00
1995	0.92	0.92	0.92	0.96	0.91	0.84	0.88	0.80	0.91	1.00
1996	0.91	0.91	0.91	0.95	0.93	0.86	0.90	0.82	0.93	1.00
1997	0.92	0.92	0.92	0.96	0.97	0.86	0.87	0.83	0.97	1.00
1998	0.94	0.94	0.94	0.96	0.96	0.87	0.89	0.85	0.96	1.00
1999	0.94	0.94	0.94	0.97	0.97	0.89	0.90	0.88	0.97	1.00
2000	0.95	0.95	0.95	0.98	0.99	0.90	0.92	0.88	0.99	1.00
2001	0.95	0.95	0.95	0.98	1.02	0.90	0.92	0.90	1.02	1.00
2002	0.98	0.98	0.98	0.99	0.98	0.92	0.93	0.92	0.98	1.00
2003	0.96	0.96	0.96	0.99	0.98	0.93	0.97	0.93	0.98	1.00
2004	0.97	0.97	0.97	0.99	1.00	0.95	0.98	0.94	1.00	1.00
2005	0.98	0.98	0.98	1.00	1.01	0.96	0.99	0.97	1.01	1.00
2006	1.00	1.00	1.00	1.00	1.00	0.98	1.06	0.97	1.00	1.00
2007	0.99	0.99	0.99	1.00	1.00	0.99	1.04	0.98	1.00	1.00
2008	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2009	1.01	1.01	1.01	1.01	1.01	1.00	0.99	1.00	1.01	1.00
2010	1.00	1.00	1.00	1.02	0.99	1.02	0.99	1.01	0.99	1.00
2011	1.00	1.00	1.00	1.02	1.02	1.04	0.99	1.02	1.02	1.00
2012	1.02	1.02	1.02	1.03	1.06	1.05	0.96	1.03	1.06	1.00
2013	1.03	1.03	1.03	1.03	0.99	1.06	0.97	1.05	0.99	1.00
2014	1.04	1.04	1.04	1.06	0.99	1.08	0.99	1.05	0.99	1.00
2015	1.06	1.06	1.06	1.06	1.01	1.10	1.04	1.04	1.01	1.00
2016	1.06	1.06	1.06	1.05	0.99	1.11	1.04	1.06	0.99	1.00
2017	1.05	1.05	1.05	1.05	0.99	1.11	1.06	1.07	0.99	1.00

3.2.4 Fertilizer

Updates to the methodology for estimating fertilizer N in the TREND 2.0 dataset are provided below. For additional details, see Byrnes et al. (2020a).

Fertilizer Use, 2013-2017: For the period 2013-2017, we now provide estimates of county-scale N fertilizer use based on national-scale estimates of N fertilizer use from the Food and Agriculture Organization of the United Nations (FAO) (Food and Agriculture Organization of the United Nations (FAO) 2022). The national-scale 2013-2017 trend, as calculated from the FAO, was then applied to individual counties, scaled to the 2012 N fertilizer use estimates. For additional details regarding estimates of N fertilizer use, see the Supplemental Information of Byrnes et al. (2020a).

Farm and non-Farm Fertilizer Use: Estimates of fertilizer use are subdivided into farm and non-farm fertilizer categories. For the period 1987-2012, the relative magnitudes of farm and non-farm fertilizer are taken from Brakebill & Gronberg (2017). For the period 1930-2011, partitioning of fertilizer use between the two categories is estimated based on the 1987-1991 mean ratio of non-farm N fertilizer use to total N fertilizer use.

Fertilizer Use Prior to 1987: For the TREND-Nitrogen 1.0 dataset, we scaled the data from 1945-1985 to obtain a smoother transition between the 1945-1985 and the 1987-2012 USGS datasets. In TREND-Nitrogen 2.0, we removed the scaling of the 1945-1985 data to preserve the national total mass and to be consistent with USGS fertilizer estimates.

4.0 Error Correction

Where appropriate, errors found in the original dataset were corrected, and the values reported in the TREND 2.0 dataset should be considered to be the best available estimates of county-scale N fluxes.

5.0 References

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