This supplementary material includes the following:

1) Historical state-level P fertilizer consumption.

2) P fertilizer use in different lands in this study.

3) Historical national average crop-specific P fertilizer application rate.

4) Application timing and methods.

5) Divergence between top-down and bottom-up data sources.

6) Comparison of P fertilizer consumption across multiple data sources.

7) Fertilized area percentage of P fertilizer among crops in the US.

1 Historical state-level P fertilizer consumption

Supplementary Table S1. Data sources for state-level P consumption

Data sources	Period
Mehring et al. (1957)	1930-1953
USDA (1971)	1954-1969
USDA (1977)	1976-1977
NuGIS (2021)	1987-2016

2 P fertilizer use for different land use types in this study

P fertilizer can be used for different land use types in the US, including nonfarm, permanent pasture, cropland pasture, and crops (Table S2). We followed the approach used in Cao et al. (2018) and separated the nonfarm, permanent pasture, and cropland pasture P fertilizer consumption from total consumption for each state. Based on multiple data sources, we reconstructed the fraction of P fertilizer consumption for these land uses (Table S3). The P fertilizer fractions of different land use were calculated at the national level and were linearly interpolated from 1927 to 2014, respectively. We applied these national changing trends of fraction to each state for each land use. Particularly,

according to Heffer et al. (2017), permanent pasture and cropland pasture together accounted for 4.0% of total P fertilizer consumption in the US in 2014. We used the ratio of these two pastures in 1964 to split these two pastures from 1964 to 2014. We assumed the state-level ratios before 1927 and after 2014 kept the same as the ratios of 1927 and 2014, respectively.

Supplementary Table S2. Category of P fertilizer use in the US

National / state-level P fertilizer use	Nonfarm use		Home garden, lawns, etc.
	Farm use	Non-agricultural land	Permanent pasture
		Agricultural land	Cropland pasture
			Corn
			Soybean
			Winter wheat
			Spring wheat
			Cotton
			Sorghum
			Rice
			Barley
			Durum wheat
			Others

Supplementary table S3. Data sources for P fertilizer consumption in nonfarm, permanent pasture, and cropland pasture.

Data sources	Period	Land uses	Resolution

Mehring et al. (1957)	1927, 1938, 1942, 1946, 1950	3[a]	Nation
USDA (1957)	1954	3[a]	State
Ibach et al. (1964)	1959	3[a]	State
Ibach and Adams (1967)	1964	3[a]	State
Brakebill and Grinberg (2017)	1987-2012	1[b]	County
Heffer et al. (2017)	2015	2[c]	Nation

The number of land uses recorded in different sources varied. [a] includes nonfarm, permanent pasture, and cropland pasture. [b] only includes nonfarm. [c] includes permanent pasture and cropland pasture.

3 Historical national average crop-specific P fertilizer application rate

National average crop-specific P fertilizer application rates from Mehring et al. (1957) include seven crop types, corn, soybeans, wheat (sum of P fertilizer use in spring wheat, winter wheat, and durum wheat), cotton, rice, barley, and cropland pasture. In comparison, USDA (1957), Ibach and Adams (1967), and USDA-ERS (2019) provided P fertilizer application rate in all nine major crops for 1954, 1959, and 1964, including three wheat types and cropland pasture. For the period from 1964 to 2022, USDA reported all nine major crops without cropland pasture. In addition, crop-specific P use reported by Mehring et al. (1957) includes the sum of nitrogen, P, potassium, and trace nutrient fertilizers (Table S4).

Supplementary table S4. Data sources for national average crop-specific P fertilizer application rate

Data sources	Period	Crop types	Data form
Mehring et al. (1957)	1927, 1938, 1942, 1946, 1950	7[a]	Total fertilizer consumption
USDA (1957)	1954	10[b]	P use rate

Ibach et al., (1964)	1959	10[b]	P use rate
Ibach and Adams. (1967)	1964	10[b]	P use rate
USDA-ERS (2019) and -NASS (2024)	1965-2022	9[c]	P use rate

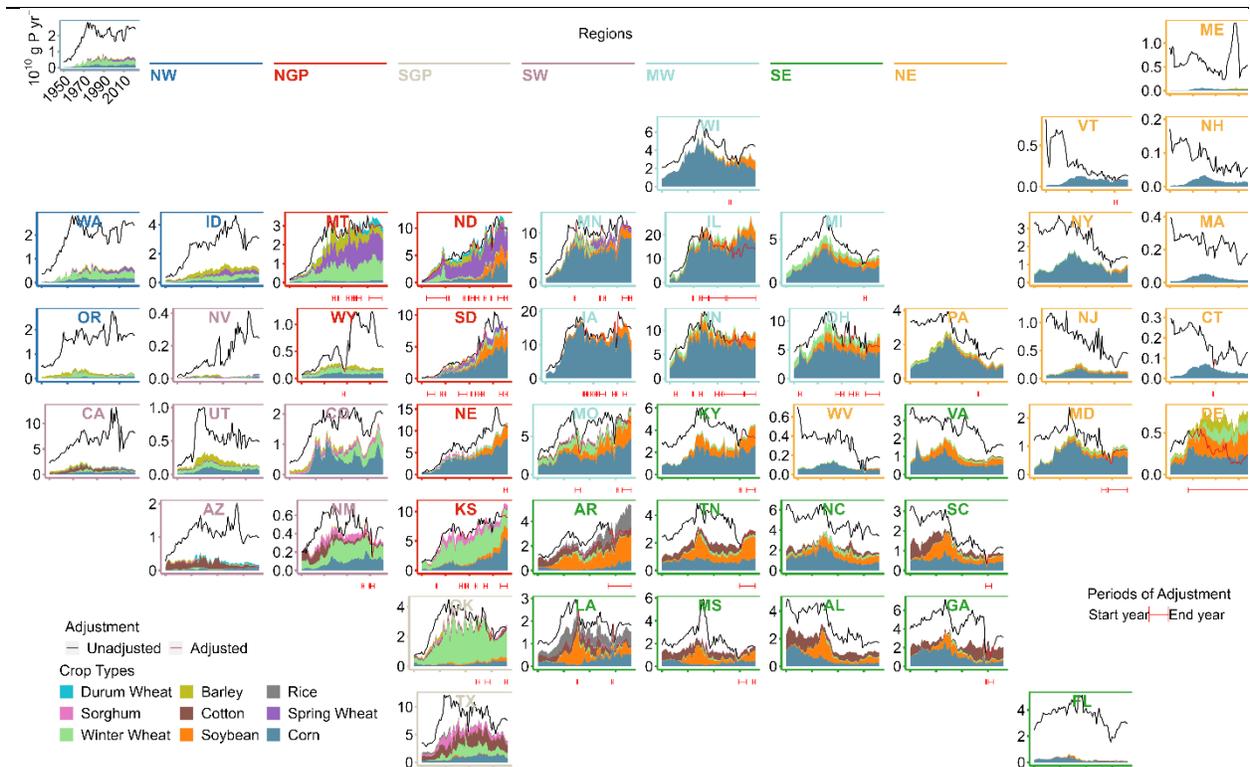
The number of crop types recorded in different sources varied. [a], crops included corn, soybeans, wheat (spring wheat, winter wheat, and durum wheat in total), cotton, rice, barley, and cropland pasture. [b], crops included all nine major crops and cropland pasture. [c], crops only included nine major crops but not cropland pasture. Total fertilizer of each crop type reported in Mehring et al. (1957) contained all N, P, K, and trace fertilizers.

4 Application timing and method

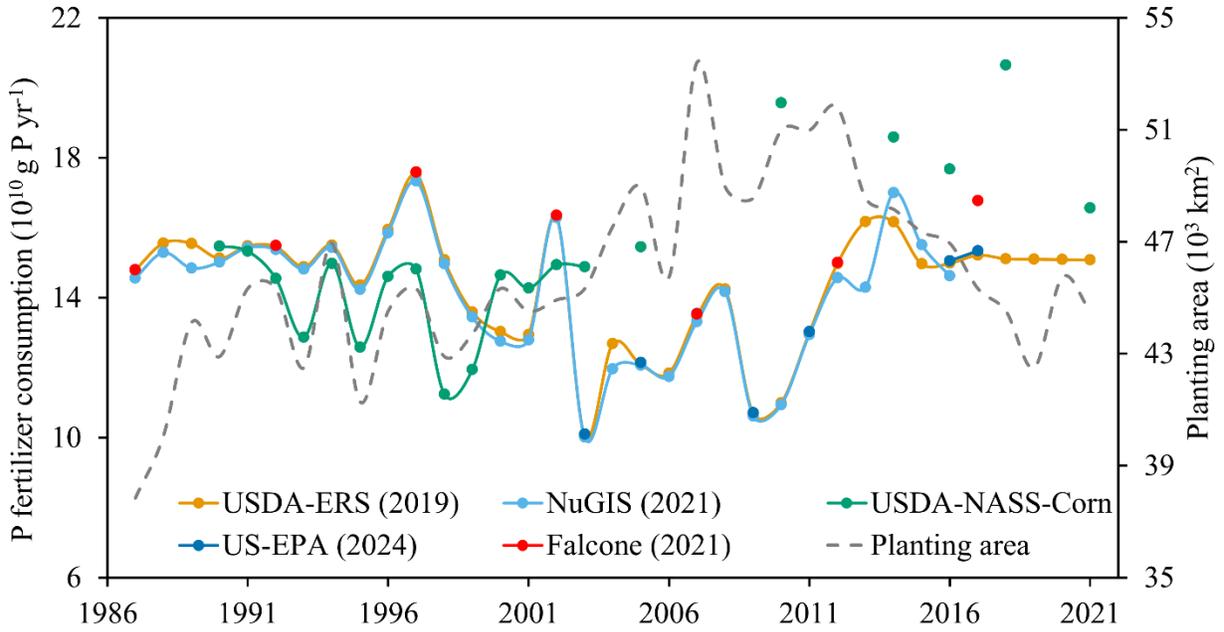
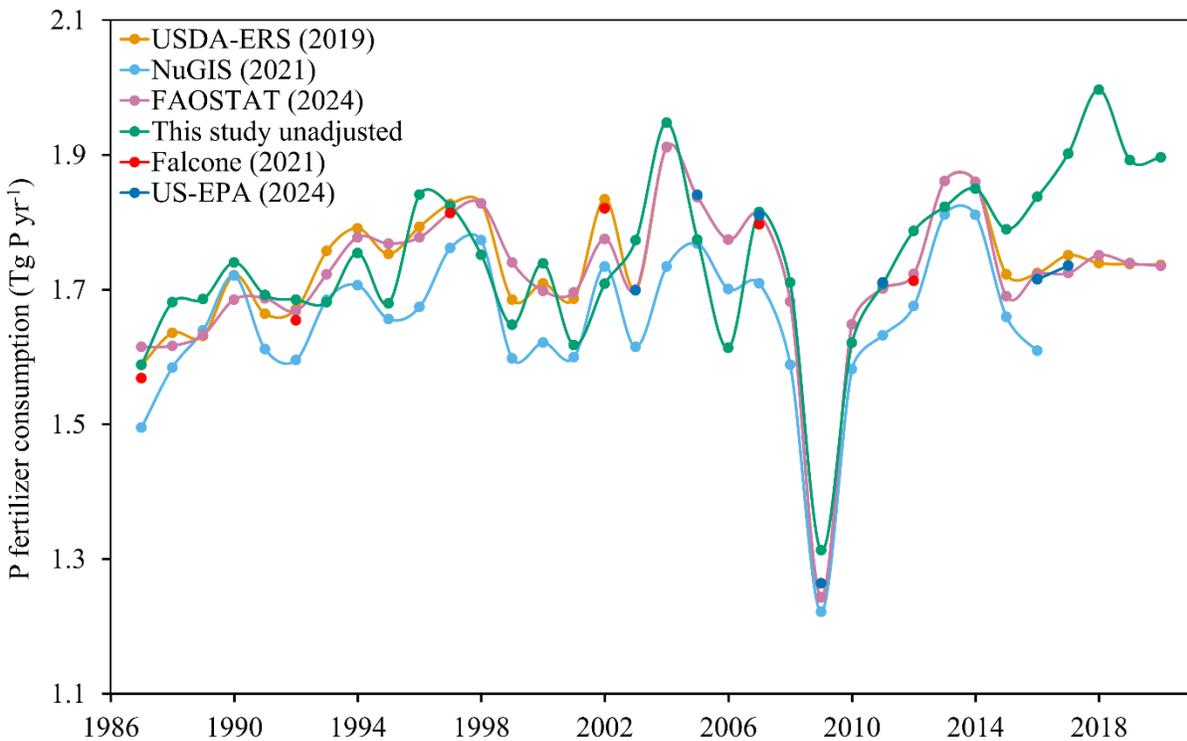
We derived P fertilizer application timing and method information from the survey conducted by USDA-ERS (2019). The survey started in 1996 and collected the data periodically for each crop in each state (Table S5). The surveyed years of different crop types in different states might vary.

Supplementary Table S5. The survey years of application timing and method for nine crops

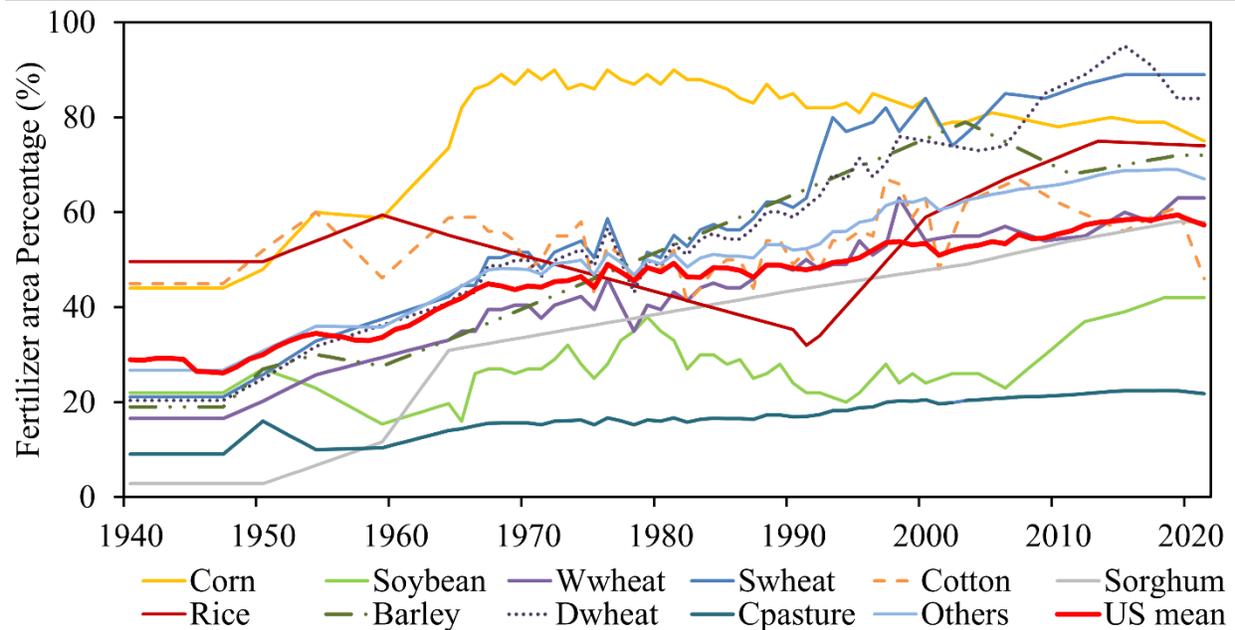
Crops	Survey years
Corn	1996-2001, 2005, 2010
Soybeans	1996-2000, 2002, 2006, 2012
Winter Wheat	1996-1998, 2000, 2004, 2009
Spring Wheat	1996-1998, 2000, 2004, 2009
Cotton	1996-2000, 2003, 2007
Sorghum	2003, 2011
Rice	2006, 2013
Barley	2003, 2011
Durum Wheat	1996-1998, 2000, 2004, 2009

5 Divergence between top-down and bottom-up data sources

Supplementary Figure 1. Time-series of P fertilizer consumption for each state and 9 major crops from 1950 to 2022. The line in each chart is state total P fertilizer consumption based on sales information from the top-down source. The red and black colors distinguish between the periods that have been modified and those that have not. The red line with two segments beneath each chart marks the adjustment period. Seven regions include Northwest (NW), Northern Great Plains (NGP), Southern Great Plains (SGP), Southwest (SW), Midwest (MW), Southeast (SE), and Northeast (NE).

6 Comparison of P fertilizer consumption across multiple data sources

In Illinois, the state total consumption, as derived from sales information from different top-down sources, exhibited consistent fluctuations during 1986-2021 (Fig. S2). The USDA-NASS (2024) surveyed P fertilizer consumption in corn closely mirrored the state total consumption from 1986 to 2003, aligning with the change in planting area. However, the P consumption of corn largely exceeded state total consumption after 2003, even amidst a substantial decrease in the planting area since 2010. This discrepancy indicates a large disparity between top-down and bottom-up sources. Given the consistency among diverse top-down sources and the mismatch between P consumption and planting area of corn, we adjusted the P fertilizer use rate of corn to bring the P consumption of corn smaller than the state total.

Supplementary Figure 2. Time-series of P fertilizer consumption in corn against total consumption by multiple data sources from 1987 to 2021 in Illinois. NuGIS (2021) only displays farm-used P fertilizer amount. The P consumption of corn was derived from USDA-NASS Quick Stats, which is the raw data we used for interpolation.

Supplementary Figure 3. Time-series of US total P consumption from 1987 to 2020 in multiple data sources. NuGIS (2021) only displays farm-used P fertilizer amount. The P consumption in

this study (green line) is the sum of cropland pasture, non-farm, permanent pasture, and interpolated major crops by excluding Other Crops.

7 Fertilized area percentage of P fertilizer among crops in the US

Supplementary Figure 4. Changes in fertilized area percentage of P fertilizer use among crops from 1940 to 2022. Wwheat is winter wheat. Swheat is spring wheat. Dwheat is durum wheat. Cpasture is cropland pasture. US mean is the average of all crops.

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