

Responses to comments from reviewer

Reviewer 1

This manuscript is built-upon the anthropogenic nitrogen input dataset (HaNi product; Tian et al., 2022), and reconstructs a comprehensive dataset with high spatial resolution (5 arc-minutes) of anthropogenic phosphorus input (mineral fertilizer, manure, and atmospheric deposition) history from 1860 to 2019 over the global terrestrial biosphere. Given the importance of phosphorus as a limiting element and the urgency of the current global phosphorus planetary boundary, long-term and spatially explicit anthropogenic P input datasets are valuable. The manuscript is well constructed and written. However, there are several major issues on methodology should be addressed.

Response: We sincerely thank the reviewer for the detailed and constructive comments. We appreciate the recognition of the significance and potential value of the HaPi dataset for the global change research community.

Comment 1: L145: Annual national P fertilizer inputs from FAOSTAT, constant country/regional specific fertilizer partitioning rate to cropland and pasture, and crop-specific fertilization rates by 2000 from Mueller et al., 2012 were used to derive gridded cropland and pasture fertilizer application. The authors used crop-specific fertilization rates from 2000 provided by Mueller et al. (2012) as a base dataset and back-calculates fertilization amounts from 1961 to 2020 by combining FAOSTAT national total P fertilizer amount. This method relies heavily on the accuracy of the 2000 data. It is not clear (1) how Mueller et al. (2012) dataset is different from Nguyen et al., 2024; (2) why not use Nguyen et al., 2024; (3) how they are different from crop-specific fertilizer use for several periods provided by FUBC1-9 (Ludemann et al., 2024). It should be noted that P fertilizer application rate for a crop can change a lot across the time. Assuming a constant rate is a strong assumption that needs further justification and discussion.

Response: Thanks for raising this important issue. Mueller et al. (2012) provide one of the most widely used spatially explicit datasets of crop-specific nutrient application rates for the year 2000 (hereafter referred to as the MFM dataset). Nguyen et al. (2024) subsequently updated this dataset and developed the NPKGRID dataset for the year of 2020 by incorporating national and subnational fertilizer census statistics 2006–2020 to adjust the gridded MFM dataset. In essence, the development of NPKGRID relies on a similar spatialization approach as our study, in which national statistical data are used to scale a baseline spatial dataset. As a result, the within-country spatial distribution of fertilizer application rates in NPKGRID largely inherits the spatial patterns from the original MFM dataset. Nguyen et al. (2024) acknowledge this limitation in their study, assuming that the relative spatial patterns of fertilizer use remain consistent with those in MFM. Therefore, despite the temporal update in NPKGRID, its spatial structure largely reflects the baseline patterns of the MFM dataset.

Given that both datasets rely on the same spatial baseline, using NPKGRID would not substantially change the spatial allocation pattern compared with MFM. Moreover, our study reconstructs P inputs for a long-term period, therefore, selecting a midpoint year (2000) as the spatial baseline provides a balanced reference for both historical reconstruction and recent decades.

While MFM and GRIDNPK are both gridded data, the FUBC1–9 dataset (Ludemann et al., 2024) provides national-scale nutrient budget estimates rather than spatially explicit fertilizer application rates. These data offer valuable information on fertilizer use at the country level, but they do not provide spatially explicit information on fertilizer application within countries. The development of the HaPi dataset requires gridded baseline information to capture spatial heterogeneity in fertilizer applications at sub-national scale. Therefore, a spatially explicit dataset such as MFM is necessary as the base layer for our reconstruction.

Regarding the assumption of constant spatial fertilizer application rates, we would like to clarify that the MFM dataset is used only as a spatial template for crop-specific fertilizer distribution in the base year. Annual fertilizer application rates are subsequently adjusted using FAOSTAT national fertilizer statistics, which allows the total fertilizer input and the implied crop-level application rates to vary over time. Therefore, the temporal dynamics of fertilizer use are captured through national statistics, while the spatial pattern is constrained by the baseline dataset. However, we acknowledge that this assumption ignores the relative spatial pattern changes in fertilizer usage for a specific crop within a country. We further discussed the limitation of this assumption in the revised manuscript (L539-543).

The fertilizer input dataset was developed using the spatial distribution of crop-specific fertilizer application rates around the year 2000 as a baseline map. Although fertilizer application rates vary over time through scaling with national statistics, this approach may disregard subnational variability in fertilizer application rates for each crop.

Comment 2: Furthermore, as described in Zou et al. (2022) cited by the authors, national-scale P fertilizer application intensity follows the environmental Kuznets curve, so that assuming P fertilization per unit area remains constant over time may be unreasonable. In addition, the constant partitioning rate between crop fertilizer use and pasture use (country or region specific value) is a coarse estimate, and could be wrong given the changes in the importance of crops/pasture in a country. For example, FUBC1-9 (Ludemann et al., 2024) provide fertilizer used for pasture/grasses for a few countries.

Response: We apologize for the lack of clarity in the original description of our methodology. Developing a long-term time series of P fertilizer inputs is essential because global fertilizer use has increased substantially since the mid-20th century. Although the MFM dataset provides crop-specific fertilizer application rates around the year 2000, these values are used only as a baseline spatial pattern in our study. The fertilizer application rates are subsequently scaled using annual national fertilizer consumption statistics from FAOSTAT, allowing the dataset to capture

the substantial temporal changes in fertilizer use from 1860 to 2020. Therefore, the P fertilizer application rates in our dataset are not assumed to be constant over time.

We also clarify that the partitioning of fertilizer use between cropland and pasture is not fixed. Instead, we applied time-varying partitioning rates from 1961 to 2019 (Figure R1) derived from previous studies, including Einarsson et al. (2021) and Lassaletta et al. (2014). These datasets provide historical estimates of fertilizer allocation between cropland and pasture. Using these dynamic partitioning rates allows our dataset to account for temporal changes in the relative importance of cropland and pasture fertilizer use.

The annual fractions of fertilizer use allocated to cropland and pasture for major countries from 1961 to 2019 were adopted from Einarsson et al. (2021) and Lassaletta et al. (2014). (L152-154)

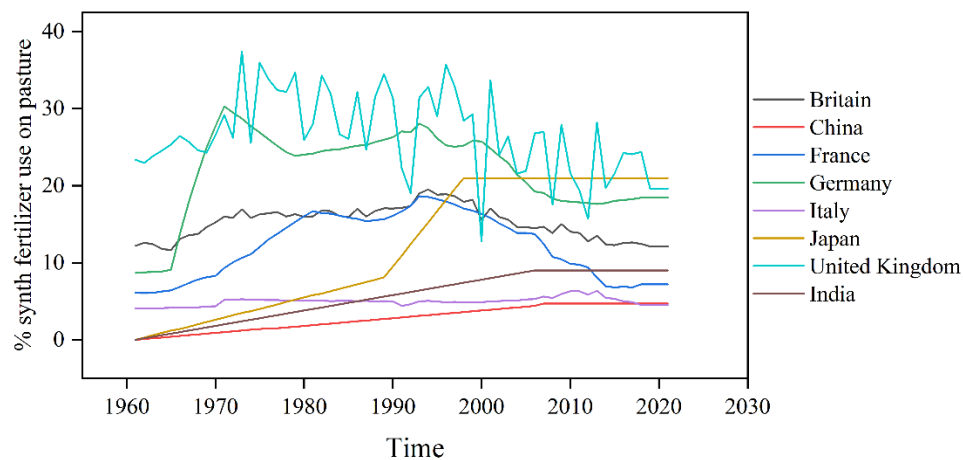


Figure R1. Percentage of total synthetic P fertilizer use applied to pasture in selected countries since 1961.

Comment 3: L169-L175: Yu et al. (2020) only provided crop distribution around 2010. Using machine learning to predict crop distribution in other years, considering that topography and soil variables will not change significantly in the short term, the changes in crop planting structure are almost only affected by changes in climate variables. The authors should further justify the method, and if there is no alternative/better choices, please discuss the limitation and uncertainties specifically and probably ways to improve the estimates.

Response: The reviewer raises a valid point regarding the primary influence of climate variables on short-term changes in crop planting structure within a grid, and the inherent uncertainties in our disaggregation method. We appreciate this opportunity to clarify our approach (Lines 175-184) and its limitations. Note that the crop distributions by Yu et al. (2020) were used only as initial inputs for starting an iterative process to obtain an optimal machine learning model in each year, which is known as Dissever algorithm (Malone et al., 2012). Though this climate-based disaggregation strategy for statistical analysis inevitably brings uncertainties, it has been usually

adopted in generating crop distribution maps (Li et al., 2025; Yu et al., 2020). In practice, to minimize these uncertainties, the machine learning-based distribution maps are adjusted or harmonized to meet multiple constraints. For example, the sum of areas of all crops in a grid should not exceed the actual arable land area, and the area of a specific farming system should not exceed the suitable area within the grid. However, A key challenge is the lack of globally consistent, dynamic maps for such constraints (e.g., yearly suitable area for specific farming systems). To improve the estimates, 1) more efforts are required for obtaining fine-grained statistics (national or provincial level statistics data is used in this study) of varied crops to improve the accuracy of the spatial allocation method; and 2) another plausible solution is to fuse satellite-retrieved crop distribution products with these statistical disaggregation maps. The major limits of this pathway are the limited temporal coverage and current lack of global availability for many crop types in these satellite products. We have added a specific discussion (Lines 544-552) of these limitations and potential improvement avenues to the manuscript.

Comment 4: L218-L220: The authors used a fixed manure N/P ratio and manure N amount to estimate manure P between 1860 and 2019. However, with changes in animal feed composition, the manure N/P ratio has varied over the past few decades for different livestock. The authors need to provide further discussion on the limitation and probably ways to improve the estimates.

Response: We apologize for not stating clearly our methodology. Here, we need to clarify that a dynamic manure N/P ratio was used for each grid, driven by livestock composition changes, throughout the study period. Annual gridded manure N/P ratio estimates were developed for 1960–2020 by accounting for temporal changes in livestock composition, despite that the relative spatial distribution pattern of each animal was fixed (based on GLW3). Because different livestock species exhibit distinct manure N/P ratios, changes in the relative abundance of livestock types (e.g., cattle, pigs, and poultry) lead to corresponding changes in the aggregated manure N/P ratio at both national and grid scales. Nevertheless, we acknowledge that the manure N/P ratio for individual livestock species may also vary over time due to changes in feed composition, livestock management practices, and nutrient use efficiency. Such temporal variations in species-specific manure N/P ratios are not explicitly represented in the current dataset because consistent long-term global observations are not available. This limitation may introduce uncertainties in the estimated manure P inputs, particularly in regions that have experienced substantial shifts in feed formulation and livestock production systems over recent decades.

We have added a discussion in the revised manuscript highlighting this limitation (Lines 253-257).

Although temporal changes in livestock composition are considered when estimating manure P:N ratios, potential changes in species-specific manure nutrient ratios associated with evolving feed composition and livestock management practices are not explicitly represented, which may introduce biases in manure P estimates.

Comment 5: L220-L223: The latest GLW dataset provide gridded data for several period based on consistent methods. This study relies only on GLW3, which neglected such variation in the past decades. I suggest the authors to revise the dataset with the latest GLW4.

Response: According to your suggestion, we adopted the annual gridded livestock of the world (AGLW) dataset (Du et al., 2025) to derive gridded manure N/P ratios. The AGLW dataset covers 1961-2021 at a 5 km resolution and was developed based on annual FAOSTAT census information. But, in some areas (especially the former Soviet Union region), livestock information is missing in AGLW. Thus, for this region, we retained our previously derived gridded N/P ratio data to maintain data integrity. The fused N/P ratio distribution maps are highly consistent both spatially and temporally (Figure S1).

Regarding the FAO GLW series (GLW1-GLW4), since they include different livestock types and were generated using different algorithms (Gilbert et al., 2018; Robinson et al., 2014; Wint and Robinson, 2007), they are not appropriate for direct interpolation to produce a temporally consistent livestock product. The related methodology has been updated (L 235-243).

Livestock distribution data $Anum_{y,g,t}$ were derived by fusing the annual gridded livestock of the world (AGLW) dataset (Du et al., 2025) and a newly downscaled product. The AGLW dataset covers 1961-2021 at a 5 km resolution and was developed based on annual FAOSTAT census information using a machine learning method. But in some areas (particularly the former Soviet Union region), livestock information is missing. To fill the gaps, we used the national FAO livestock statistics and the Global Livestock of the World 3 (GLW3) database (Gilbert et al., 2018) to generate a long time-series gridded livestock distribution data.

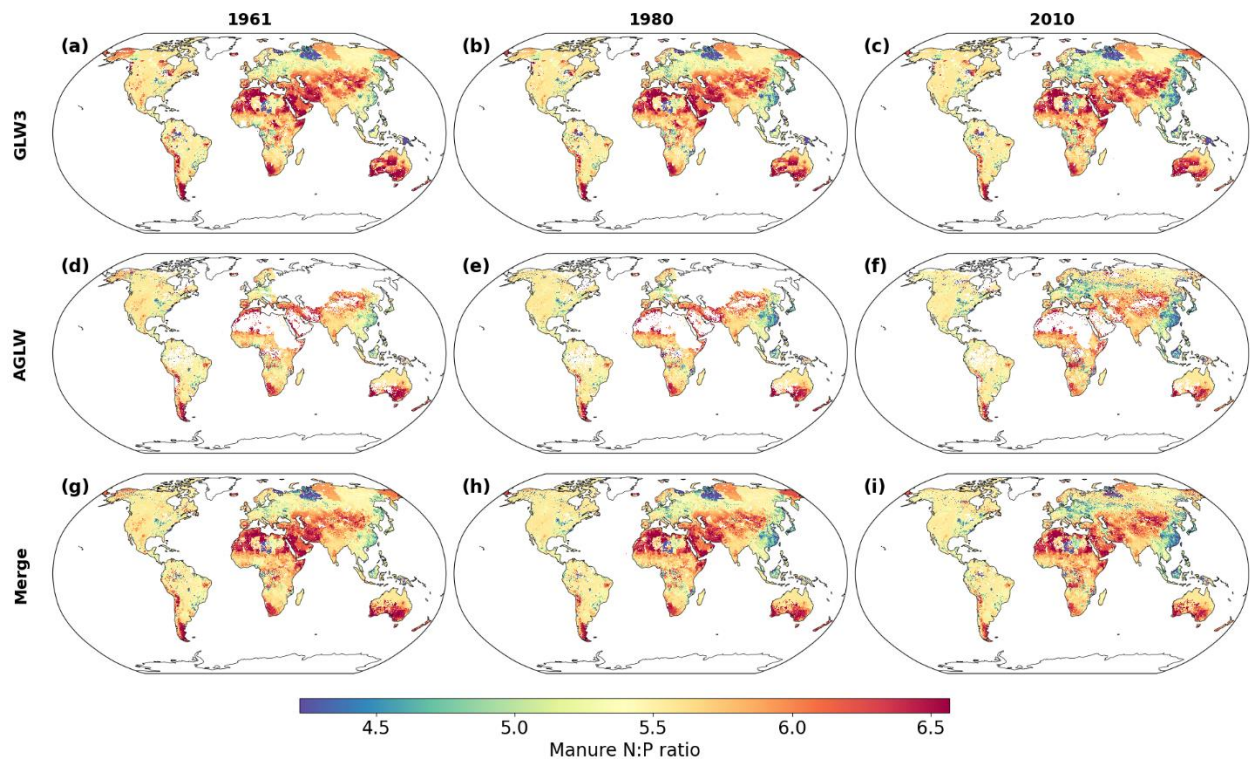


Figure S1. Comparison of manure N:P ratio maps derived from three datasets in 1961 (a, d, g), 1980 (b, e, h), and 2010 (c, f, i). The first, second, and third rows show the GLW3, AGLW, and merged datasets, respectively. Columns correspond to 1961, 1980, and 2010.

Comment 6: L236-L238: This study attributes atmospheric P deposition to both natural and anthropogenic sources, yet the title is anthropogenic Phosphorus inputs. Is it possible to derive anthropogenic P deposition (e.g., excluding pre-industrial ones?)

Response: Thanks for raising this issue. As you suggested, the atmospheric P deposition includes contributions from both natural sources (e.g., mineral dust and sea spray) and anthropogenic emissions. Although the title emphasizes anthropogenic phosphorus inputs, we retained total atmospheric deposition in the dataset for two main reasons. This is mainly because providing total deposition is more useful for data users, as many land surface and biogeochemical models require the total atmospheric P input to ecosystems rather than only the anthropogenic component. The partitioning of atmospheric P deposition to natural and anthropogenic sources in 2001-2019 is available in the work by You et al. (2026), which provides P deposition data for this study. Nevertheless, attributing the natural and anthropogenic contributions prior to 2000 still needs atmospheric transport modeling and detailed emission inventory, which obviously is out of the scope of this study.

Comment 7: L273-L274: How P deposition from 1860 to 1899 was extrapolated?

Response: In the atmospheric phosphorus deposition dataset provided by Ringeval et al. (2024), global P deposition shows relatively stable values during the early part of the twentieth century (approximately 1900–1960). Based on this pattern, we assumed that atmospheric P deposition remained approximately constant during the earlier period of 1860–1899. Therefore, the deposition values for 1860–1899 were extrapolated using the same deposition levels as those estimated for the early twentieth century.

We acknowledge that this assumption introduces some uncertainty because direct estimates of atmospheric P deposition prior to 1900 are limited. To improve transparency, we have the following content in the Method Section (L301-303).

P deposition for the period 1860–1899 was assumed to remain constant and equal to the early twentieth-century levels.

Comment 8: L333: I recommended to change the abbreviation of Southwestern South America, as SSA is easily confused with Sub-Sahara Africa.

Response: Thanks for your suggestion, and we have replaced SSA with SWSA.

Comment 9: Table 3: Zou et al. (2022) and Ludemann et al. (2024) also provide relevant results for P fertilizer and manure application, which need to be compared with the estimates from current study. In particular, Ludemann et al. provided the FAOSTAT nutrient budget reference database, and much of the data in this paper comes from FAOSTAT.

Response: Thanks for your suggestion. Following the recommendation, we have revised Table 3 to include a comparison of our estimates with those reported by Zou et al. (2022) and Ludemann et al. (2024). Overall, the global total phosphorus fertilizer input to croplands estimated in our dataset (HaPi) is in good agreement with the estimates from both studies. For manure input on croplands, our estimates are comparable to those reported by Zou et al. (2022), but are lower than those from Ludemann et al. (2024). This discrepancy is likely attributable to differences in the definition of croplands. Specifically, Ludemann et al. (2024) define croplands as the sum of arable land and temporary pastures within crop rotations, which may include a portion of manure applied to pasture systems. In contrast, our study distinguishes cropland and pasture as separate land-use categories, which may lead to lower manure inputs being attributed to croplands. In addition, FAOSTAT data undergo continuous revision and updates across different versions, leading to inconsistencies between datasets from different release periods.

Table 3. Comparison of P input data with other global estimates

Global P inputs	Previous studies (Tg P Yr ⁻¹)	Year	This study (Tg P Yr ⁻¹)	Reference
Fertilizer input on cropland	16.4	2002-2010	17.6	Lun et al. (2018)
	13.8	2000	13.2	Bouwman et al. (2009)
	0.4-15.8	1900-2010	0.3-17.6	Zhang et al. (2017b)
	4.6-17.5	1961-2013	4.5-18.0	Lu and Tian (2017)
	4.5-21.0	1961-2020	4.5-19.7	Ludemann et al. (2024)
	16.8	2008-2012	16.7	Zou et al. (2022)
Fertilizer input on pasture	0.4	2002-2010	1.5	Lun et al. (2018)
Manure input on cropland	1.6-7.2	1900-2010	1.0-4.3	Zhang et al. (2017b)
	7.1	2002-2010	4.1	Lun et al. (2018)
	6.3	2005	4.0	Sattari et al. (2016)
	4.3-6.6	1961-2020	2.7-4.5	Ludemann et al. (2024)

	4.7	2008-2012	4.2	Zou et al. (2022)
Manure input on	12.7	2002-2010	13.7	Lun et al. (2018)
grassland (pasture	10.2	2005	13.7	Sattari et al. (2016)
and rangeland)				
Total manure	17.1	2000	16.8	Bouwman et al.
input				(2013)
	16.5	2005	17.7	Sattari et al. (2016)
	19.8	2002-2010	17.8	Lun et al. (2018)

Reviewer 2

This manuscript presents a rich dataset supported by substantial and careful work. The resulting anthropogenic phosphorus input dataset will help advance our understanding of the global phosphorus cycle. However, I still have several concerns regarding the data-processing methods and some important details of the dataset development. I therefore recommend major revision and hope that the authors can address these concerns in a revised manuscript.

Response: We thank the reviewer for the positive assessment of our work and for recognizing the value of the HaPi. We also appreciate the constructive suggestions regarding data validation, uncertainties, and methodology.

General comments

Comment 1: Validation is still weak (Lines 443-456). The comparison mainly focuses on global totals, and most reference datasets use the same FAOSTAT sources. This does not validate the 5-arcmin spatial patterns. I would like to see comparisons with independent national or subnational statistics for several representative regions.

Response: We thank the reviewer for this important suggestion, and we agree that evaluation against independent national or subnational statistics is desirable for assessing spatial reliability beyond global aggregates. Currently, independent P fertilizer datasets at national and subnational scales are still very limited, and FAOSTAT remains the most widely used and consistently available global source. Nevertheless, to strengthen the validation, we have further searched available datasets and identified two independent national-scale data sources: (1) the National Bureau of Statistics of China, and (2) CMH-P, a cropland P fertilizer application dataset for the United States derived from USDA-based statistical records (Cao et al., 2024).

We compared aggregated HaPi estimates with these two independent datasets. The results show that HaPi estimates are generally slightly lower than those two independent datasets, however, the temporal trajectories are highly consistent, and the magnitudes are comparable across the overlapping periods. Spatially, the P fertilizer input patterns in the HaPi dataset closely agree with those in the CMH-P dataset across the United States. These results provide additional support for the reliability of the HaPi dataset at national scales, particularly in capturing interannual variability and long-term trends. We have added the following content in the discussion section 4.1 (L463-467):

Additional validation against independent national statistics from China and the U.S. shows that HaPi captures comparable magnitudes and similar spatial-temporal patterns of P fertilizer use

(Figure S5), although with slightly lower estimates relative to both datasets. These results provide further support for the robustness of national-scale temporal dynamics in HaPi.

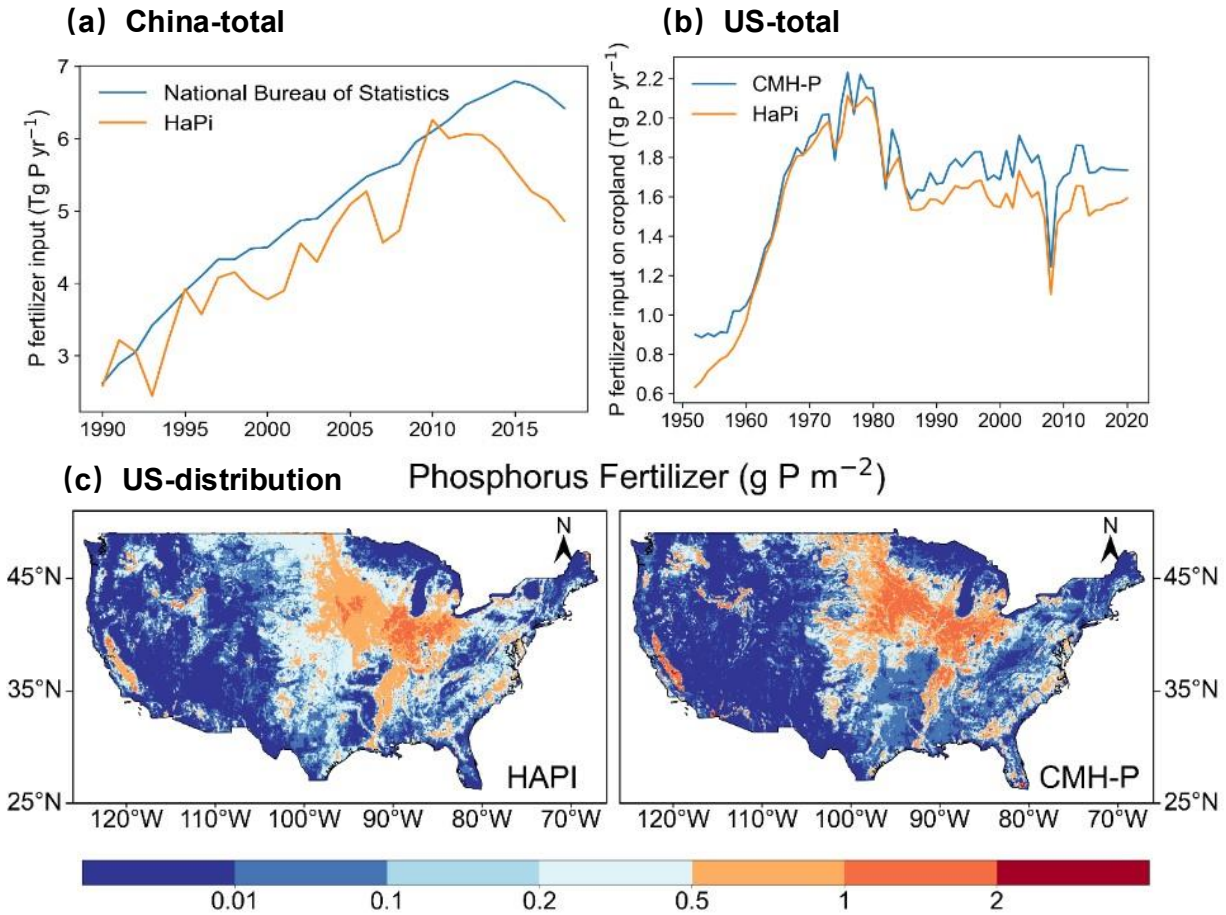


Figure S5. Comparison of P fertilizer inputs from the HaPi dataset with independent datasets: (a) national statistics for China; (b) national statistics for the United States; and (c) spatial comparison of P fertilizer inputs in the United States in 2020.

Comment 2: The estimation of manure-derived P may involve considerable uncertainty. Lines 210-230: Could the authors clarify whether the manure P estimates are sensitive to the fixed animal-specific P:N ratios and the use of GLW3 livestock spatial patterns from a single reference year? Although annual FAO livestock statistics were used to scale national livestock numbers, the within-country spatial distribution appears to remain static, which may introduce uncertainty in regions where pig and poultry production has shifted substantially over time.

Response: Thanks for this insightful comment. Reviewer 1 has also raised this issue, and we adopted the annual global gridded livestock of the world (AGLW) dataset (Du et al., 2025) to substitute the original static spatial pattern within each country. The AGLW data employs machine learning method to disaggregate FAOSTAT statistics to 5-km gridcells. However, it

lacks available livestock density, in particular in the former Soviet Union region. Thus, the original N:P ratio maps were retained for this region. The final product shows high spatial and temporal consistency (Figure S1). All data and related figures have been updated. Comparison of the results before and after updating the manure N:P ratio dataset showed no significant changes in total manure P inputs across regions or over time, suggesting that manure P estimates are relatively insensitive to variations in livestock spatial patterns. This change has been stated in the Methods section (L 235-243).

Livestock distribution data $Anum_{y,g,t}$ were derived by fusing the annual gridded livestock of the world (AGLW) dataset (Du et al., 2025) and a newly downscaled product. The AGLW dataset covers 1961-2021 at a 5 km resolution and was developed based on annual FAOSTAT census information using a machine learning method. But, in some areas (particularly the former Soviet Union region), livestock information is missing. To fill the gaps, we used the national FAO livestock statistics and the Global Livestock of the World 3 (GLW3) database (Gilbert et al., 2018) to generate a long time-series gridded livestock distribution dataset.

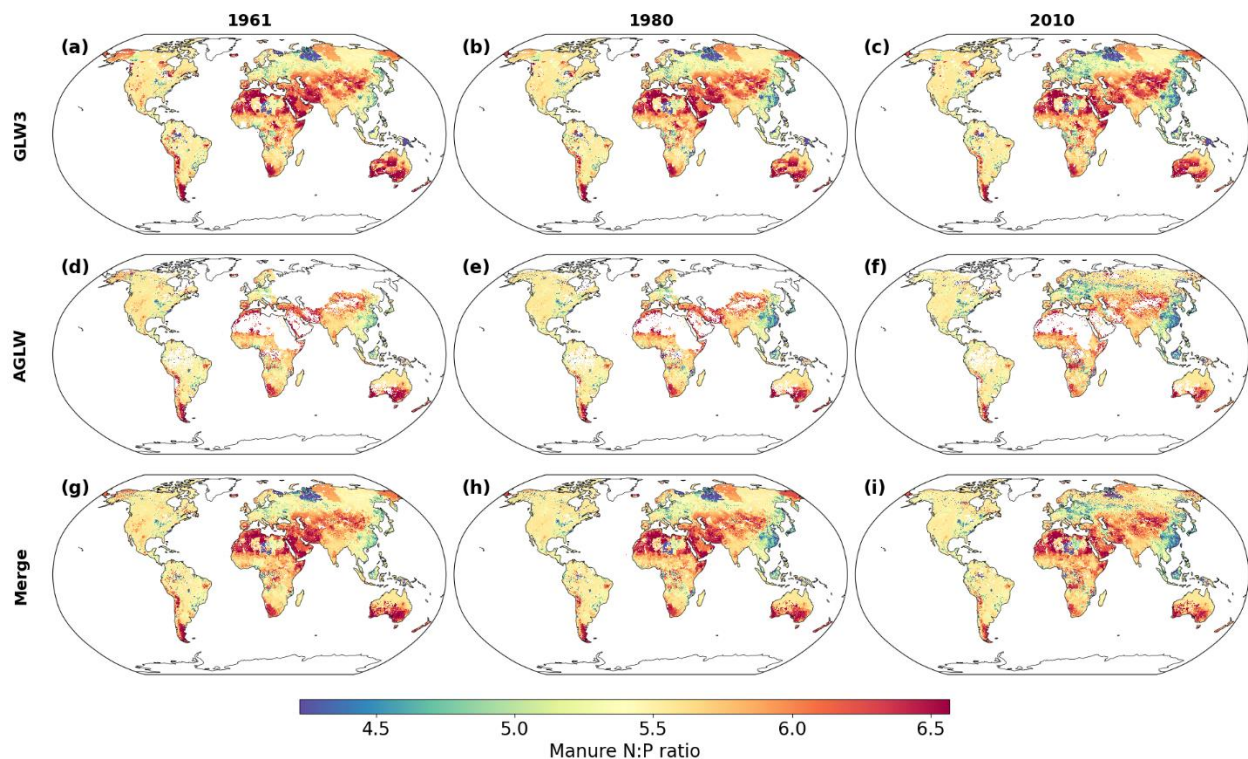


Figure S1. Comparison of manure N:P ratio maps derived from three datasets in 1961 (a, d, g), 1980 (b, e, h), and 2010 (c, f, i). The first, second, and third rows show the GLW3, AGLW, and merged datasets, respectively. Columns correspond to 1961, 1980, and 2010.

Comment 3: Lines 188-199: Uncertainty in the pre-1961 reconstruction. As I understand it, the 1961 spatial distribution was used as a reference pattern and scaled backward using the global

temporal change rates from Cordell et al. (2009). If so, the pre-1961 maps may mainly reflect changes in global total P fertilizer use, rather than changes in regional or national spatial patterns.

I do not fully understand why this approach is appropriate for extending the dataset back to 1860. In my view, applying the 1961 spatial pattern to nearly 100 years of earlier history may seriously weaken the reliability of the pre-1961 data, because crop composition, cropland distribution, fertilizer accessibility, and agricultural practices likely changed substantially during this period. I strongly suggest that the authors more carefully address the uncertainty introduced by this backward extrapolation and provide clearer information in the dataset, such as reliability classes, or confidence flags for the pre-1961 period.

Response: Thank you for raising this important issue. As correctly noted by the reviewer, the spatial distribution of fertilizer inputs in 1961 was used as the baseline map, and annual fertilizer inputs before 1961 were reconstructed by scaling this baseline using the historical global fertilizer consumption trajectory reported by Cordell et al. (2009). We acknowledge that this approach cannot explicitly capture historical changes in crop composition, fertilizer accessibility, and agricultural management practices prior to 1961. Consequently, uncertainties in the spatial distribution of fertilizer inputs are inevitably higher during this period. Although the pre-1961 estimates are associated with greater uncertainty than those after 1961, they remain valuable for Earth system and land surface modeling studies. Many land surface models require continuous forcing data from pre-industrial conditions to quantify long-term ecosystem responses and legacy effects of anthropogenic nutrient inputs.

It is important to note that globally consistent, spatially explicit fertilizer datasets before 1961 are extremely limited. Under such circumstances, the use of a baseline spatial distribution combined with historical fertilizer consumption trajectories provides a pragmatic first-order reconstruction that enables the extension of the dataset back to the pre-industrial period. Similar reconstruction strategies have been adopted in many global nutrient input datasets when long-term spatial observations are unavailable (Batoool et al., 2025; Xu et al., 2019). Critically, the global consumption of inorganic P fertilizer was limited before the 1960s. Prior to the 1960s, P fertilizer use was negligible in most regions, meaning that the spatial pattern observed in 1961 largely reflects the regions that had both the accessibility and the demand for P fertilizers at the time when large-scale fertilizer use began. This historical context supports the assumption that these early-adopting regions are representative of the priority areas for P fertilizer application in preceding decades.

Meanwhile, according to your suggestion, we have revised the manuscript to clarify the reconstruction procedure, expanded the discussion of uncertainties associated with the pre-1961 period, and added temporal confidence classes in the dataset documentation to distinguish between the lower-confidence reconstruction period (1860–1960) and the period constrained by annual national fertilizer statistics (1961–2020).

Although this approach provides a temporally continuous long-term dataset, it cannot explicitly represent historical changes in crop composition, fertilizer accessibility, and agricultural management practices, and it ignores regional variations in the changes of P fertilizer usage across different countries before 1961. Consequently, uncertainties are substantially higher in the pre-1961 period, and the resulting maps should be interpreted primarily as broad-scale reconstructions rather than precise representations of historical subnational fertilizer distributions. (L563-570)

Table R1. Confidence flags of HaPi data in different periods

Year	Confidence Flag	Description
1860–1960	1	Lower confidence: reconstructed using historical global fertilizer consumption trajectories and the 1961 baseline spatial pattern
1961–2020	2	Higher confidence: constrained by annual national fertilizer statistics

Minor comments

Comment 4: Lines 34-55 and 233-246: HaPi is described as an “anthropogenic” P dataset, but atmospheric deposition includes dust, sea salt, volcanoes, and other natural sources. The terminology should be reconsidered.

Response: Thank you for pointing out this inconsistency. We use the term anthropogenic P inputs because the dominant P inputs represented in the HaPi dataset are anthropogenic, whereas natural atmospheric deposition contributes only a small fraction of the total P inputs. Moreover, using the term total P inputs would also be inappropriate because another major natural P source, weathering, is not included in the dataset. Therefore, we retain the term anthropogenic P inputs while clarifying in the revised manuscript that it primarily refers to the dominant anthropogenic input pathways, and that the atmospheric deposition component includes both natural and anthropogenic sources.

Although the HaPi dataset primarily focuses on anthropogenic P inputs, it additionally includes both natural and anthropogenic sources. (L606-607)

Comment 5: Lines 145-154: The manuscript states that 18 crops were included, but only 17 are listed. Please check the crop list.

Response: Thanks for your careful check, and 17 is the correct number.

Comment 6: Lines 182-185 and Table 1: The land-use data are reported to end in 2019, while HaPi continues to 2020. How was the 2020 land-use map produced?

Response: We used the HYDE 3.3 and LUH2 land use datasets in our analysis. We apologize for the earlier misstatement in which we incorrectly referred to HYDE 3.3 as HYDE 3.2. We confirm that HYDE 3.3 was the version actually used in our calculations.

For the period prior to 1949, HYDE 3.3 (<https://landuse.sites.uu.nl/datasets/>) provides land use maps only at decadal intervals (i.e., one map every ten years). To generate continuous annual data, we applied a temporal downscaling approach: the LUHv2 data for each year within a given decade were used to proportionally interpolate the HYDE 3.3 map from the beginning of that decade. This method preserves the decadal baseline provided by HYDE 3.3 while incorporating the interannual variability captured by LUHv2.

We have corrected the dataset version reference in the revised manuscript and clarified this reconciling procedure in the Methods section (L193-201).

Comment 7: Lines 233-263: The atmospheric deposition period is inconsistent: 2001-2019, 2000-2019, and extension back to 1900 are all mentioned. The treatment of 1860-1899 and 2020 should be explained.

Response: In the atmospheric phosphorus deposition dataset provided by Ringeval et al. (2024), global P deposition shows relatively stable values during the early part of the twentieth century (approximately 1900–1960). Based on this pattern, we assumed that atmospheric P deposition remained approximately constant during the earlier period of 1860–1899. Therefore, the deposition values for 1860–1899 were extrapolated using the same deposition levels as those estimated for the early twentieth century. We acknowledge that this assumption introduces some uncertainty because direct estimates of atmospheric P deposition prior to 1900 are limited. To improve transparency, we have the following content in the Method Section (L301-303).

P deposition for the period 1860–1899 was assumed to remain constant and equal to the early twentieth-century levels.

Comment 8: Lines 247-263: Downscaling 2.5° model output to 5 arcmin does not necessarily provide real information at 5-arcmin resolution. The authors should avoid overstating the effective resolution.

Response: Exactly as the reviewer pointed out, downscaling coarser-resolution model outputs to a finer grid does not necessarily generate meaningful information at the finer resolution. In this study, the 5-arcmin product was generated to provide a spatially consistent input dataset compatible with other high-resolution forcing datasets. The downscaling approach and resulting products were rigorously evaluated against site-level observations in You et al. (2026), demonstrating reasonable performance at the annual timescale.

Comment 9: Lines 525-537: Could the authors briefly justify the use of a uniform 20% uncertainty for FAO-based data? Data quality may vary across countries, time periods, and variables, so a short explanation would be helpful.

Response: Thanks for raising this issue. Dr. Francesco N. Tubiello, one of our co-authors and the developer of the FAO survey data, suggests that while it is correct that uncertainty of FAO activity data varies by country or at least region (and theme), FAO does not have a firm hold on these numbers. FAO routinely uses a 20% uncertainty across the board as a default assumption, which is recommended by IPCC to use for national greenhouse gas inventories (NGHGs) using FAO activity data as input (Tubiello et al., 2021). In addition, a more exhaustive assessment of uncertainty in FAO land use data by country and region –resulting in about 25% uncertainty globally- is given in Tubiello et al. (2023). We acknowledge that a uniform 20% uncertainty cannot fully capture the spatial and temporal heterogeneity in data quality. Nevertheless, it provides a pragmatic first-order approximation of the uncertainty associated with the underlying statistical data.

Comment 10: Line 378: “Consumer of manure P” is not appropriate because manure application and deposition are inputs rather than consumption. “Manure P input” would be clearer.

Response: Thanks for your suggestion. We have revised this sentence as “China has surpassed Europe as the region receiving the largest manure P inputs since the 2000s, as manure P inputs in Europe have declined since the 1980s.”

References

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