RESPONSE TO REVIEWERS' COMMENTS

Anonymous Referee #2

Understanding and assessing the spatiotemporal patterns in crop-specific phosphorus (P) fertilizer management is crucial for promoting crop yield and mitigating environmental problems. This manuscript combined the top-down and bottom-up method as well as data source to rebuild the crop-specific P fertilizer inputs from 1850 to 2022. I believe it could be highly interesting for readers and related researchers. Before publication, there are still some problems as follows:

Response: We appreciate the reviewer's interest in this work and for the insightful comments.

In the line 157-165, you mentioned that "the summed P consumption of 9 major crops exceeds the state total P amount in some states", and "the negative rates of the Other Crops were replaced by the average". Thus, the total amount of P consumption could be increased, and do you have updated the increased parts for the county level or the state level?

Response: We thank the review for pointing out the unclear description. In our analysis, when "the summed P consumption of 9 major crops exceeds the state total P amount in some states", we adjusted only these nine main crops to align with the total consumption, without changing values in total P consumption. This approach is based on our assumption that total P fertilizer consumption data from sales (top-down source) are more reliable than other data sources. The specific steps are as follows: if, in any state, the sum of P fertilizer consumption of nine main crops exceeds the total state P fertilizer consumption, which result in a negative values of P fertilizer consumption in other crops (total P fertilizer consumption minus P fertilizer consumption of nine main crops), we replaced negative values of P fertilizer rate for other crops with either a 10-year moving average or the interpolated values, and further adjust the values of main crops to match the total P fertilizer amount. We have revised the description in lines 161-173.

Lines161-173: "We adjusted the crop-specific application rates of major crops to match the state total P consumption by assuming that total P consumption data from top-down source is more reliable. First, we reconstructed the positive application rates of Other Crops in each state. If the

10-year moving average of the positive application rates of the Other Crops was available, we used it to replace the negative rates of the Other Crops. Otherwise, if the moving average was unavailable, we interpolated the gaps using the area-weighted mean of Other Crops across all states within the corresponding region as the reference trend. The selection of Eq. (1) and Eq. (2) for interpolation depends on the availability of the beginning and ending year of the gap. After excluding the P fertilizer consumption of cropland pasture, Other Crops, permanent pasture, and non-farm uses from the state total P consumption, we used the remaining total consumption to scale the crop-specific P fertilizer application rates for major crops."

In your study, you have estimated the crop-specific P application rate, and then you have converted the unit of P use from cropland area to land area. It could be very confused. If one grid with less cropland but higher P application rate, it could be presented very low P use.

Response: We appreciate this point. As the reviewer noted, it is true that a grid with less cropland but a high P fertilizer rate will appear to have a low P rate on the map when we use total land area for spatialization instead of cropland area. We have compared the P application rate maps using total land area versus cropland area, and both maps have their pros and cons. For the maps using cropland area, a high fertilization rate in grids with low percentage of cropland may mislead the readers by showing a high level of P fertilizer input in such areas. Ultimately, we opted to convert the cropland area to land area for the following reasons: (1) It presents a clear overall spatial patterns of P application rate, with hotspots representing both high-levels of P fertilizer use rate and larger cropland acreage. (2) It facilitates future studies in identifying and comparing the levels of P fertilizer received by per unit land area on map, using the same land basis. Potential users may use this P fertilizer database to drive ecosystem/environmental models to quantify plant growth, environmental quality, etc. In such cases, presenting the P application rate across all land areas simplifies the way to use the database and minimizes potential errors (e.g., discrepancies arising from using different land use datasets) for other researchers. (3) The application rate can be easily transferred to consumption by timing the map to gridded land area with no need to consider the cropland density in each grid. Vice versa, this data product can be converted to P fertilizer use rate on per unit cropland area by lining up with our crop type and area database (Ye et al., 2024). We included this statement in the figure captions.

The result section is not enough to present your studies, especially for changes and reason on the magnitude and spatiotemporal of P fertilizer use. The increase of P fertilizer use can be due to crop change or the increase of application rate, and thus I believe it could be some points on these reasons.

Response: We agree that the changes in P fertilizer use can be attributed to various factors. In the Result section 3.1, we concisely illustrated the patterns of P fertilizer use change across crops over time and space. In the Discussion section 4.2, we systematically examined the potential causes contributing to these spatiotemporal patterns. From 1850 to 1940, the increasing application rate among crops was the primary drivers of the rising P fertilizer use. After 1940, both changes in application rate and spatial cropland distribution significantly influenced the temporal change in P application rate. As suggested by reviewer in the below comment, we have added a stacked area plot of P consumption by different crops from 1930 to 2022, providing an additional perspective on the contribution of different crops.

The section of "Patterns of P fertilizer application timings" and "Patterns of P fertilizer application methods" are too short, and I suggested to add some interesting results.

Response: We appreciate this suggestion. Our current results just show the shares of different timings and methods across crops and space. To present the practice-specific application rate, we calculated the P fertilizer rate for different timing and method by multiplying annual P fertilizer application rate with the respective fractions for each timing and method. We replaced the original figures depicting the fractions of application timings and methods (previously Figures 7 and 8) with a newly plotted figure because it is more informative and meaningful. The original figures have been renumbered to Figures S4 and S5. Please see our statement about P fertilizer rates in different timings and methods in lines 275-282 and lines 290-295.

Lines 275-282: "In contrast to the wider distribution of different timing ratios, the hotspots of P application rate for 4 timings were found in the Midwest, the Great Plains, and the rice-belt due to generally low application rate in other regions (Fig. 7). Intense P fertilizer was applied in the fall in the Midwest (> 0.6 g P m^{-2}) (Fig. 7a), particularly in Iowa and Illinois. Spring application

was concentrated in the corn-belt and rice belt with rates greater than 0.5 g P m^{-2} (Fig. 7b). Farmers in the Northern Great Plains, Kansas, Indiana, and Wisconsin favored application at planting (Fig. 7c). After planting applications were minimal (< 0.2 g P m^{-2}) in the rice-belt and Nebraska (Fig. 7d)."

Lines 290-295: "Due to the intense use of P fertilizer in the corn-belt and rice-belt, the hotspots of P application rate (> 0.6 g P m^{-2}) for 3 methods were found in various regions within these two belts (Fig. 8). Non-broadcast application is prevalent in the Northern Great Plains, Kansas, and Minnesota (Fig. 8a). Intense application of P fertilizer via broadcast with incorporation was observed in Minnesota and Illinois (Fig. 8b). The corn-belt and rice-belt received most of their P fertilizer through broadcast without incorporation (Fig. 8c)."

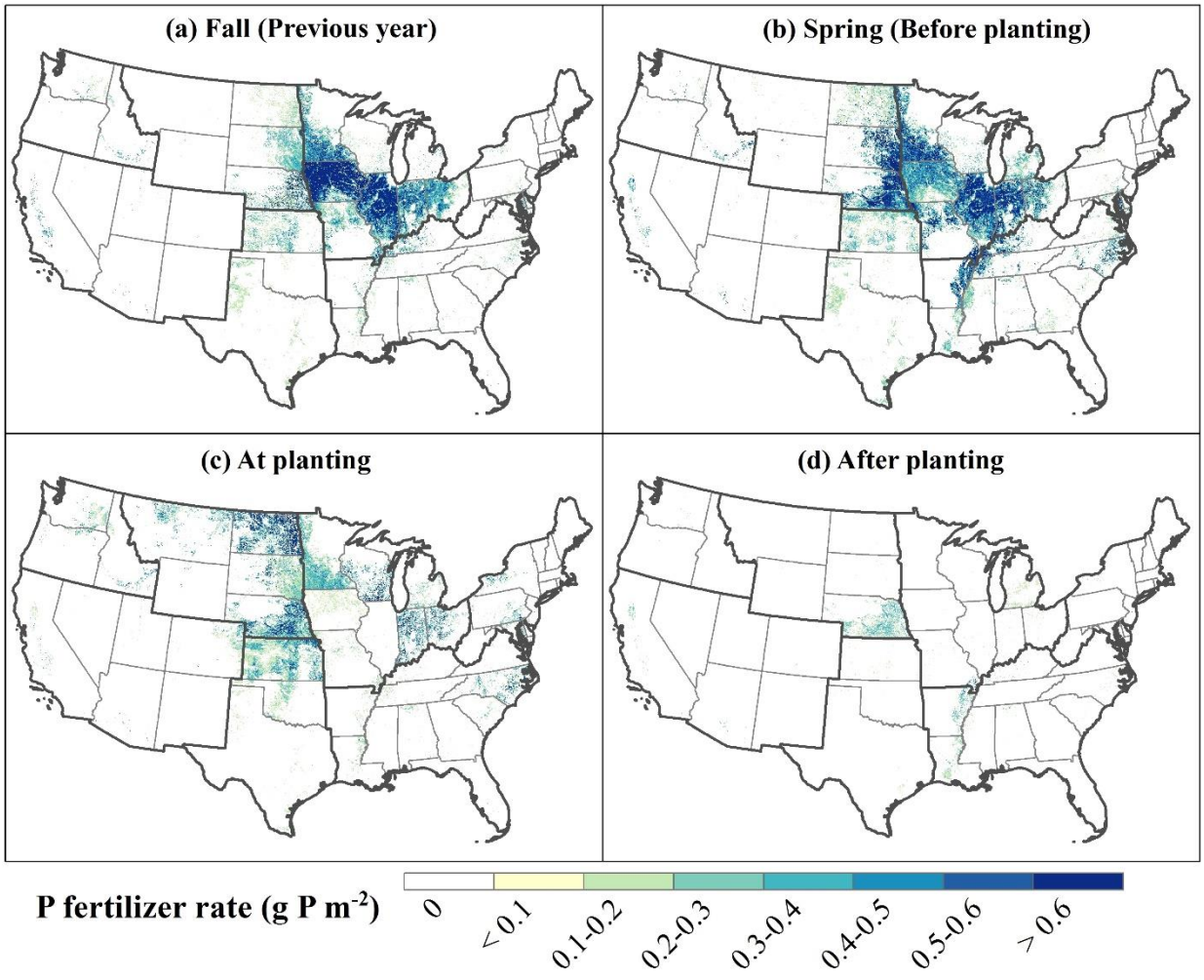


Figure 7. Spatial distribution of P fertilizer application rates at four application timings across the contiguous US in 2020.

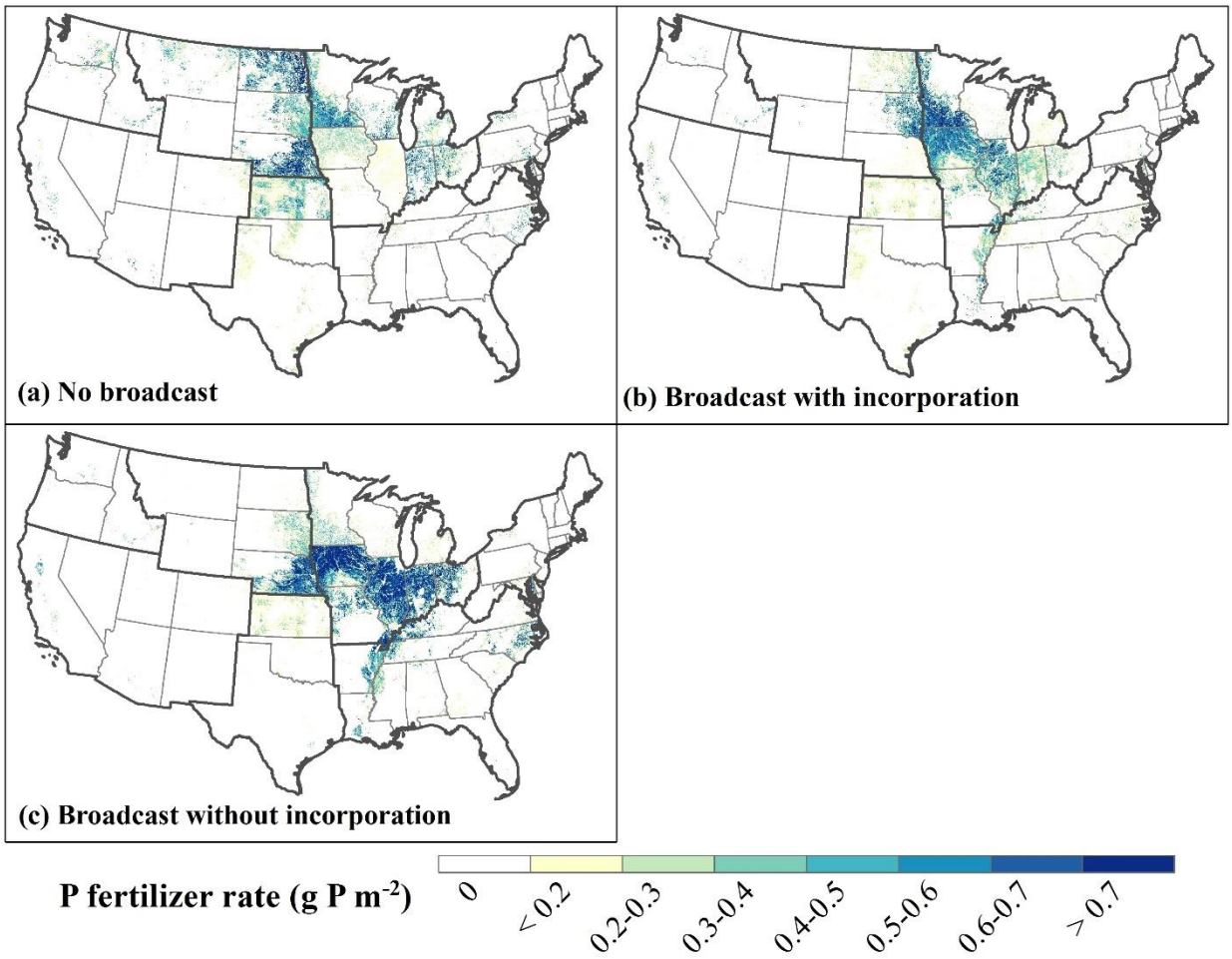
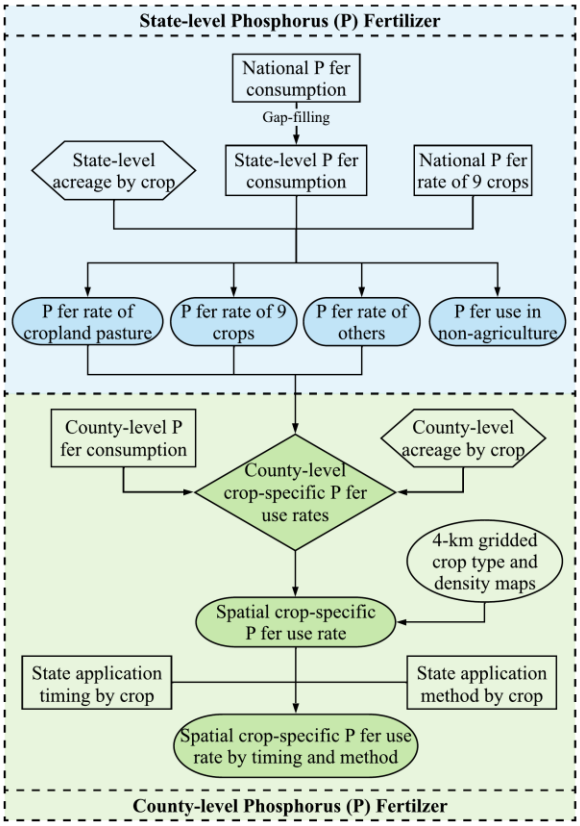


Figure 8. Spatial distribution of P fertilizer application rates in three application methods across the contiguous US in 2020.

Figure 1 is not easy to readable, suggest to improve it.

Response: We thank the reviewer for this suggestion. We have revised Figure 1 to enhance its readability by simplifying the original looping structure and adopting a hierarchical layout. Please see our attached figure below:



It is highly confused in Figure 2 (b). The light-colored bars denote the application rate on fertilized area and dark-colored bars show the application rate on all cropland. Thus, the light-colored bar should be higher than the dark-colored bar. However, the light-colored bar and the dark-colored bar are cumulative, and thus I am confused for the light-colored bar? Is it from the bottom (0 g P m-2) or the top of the dark-colored bar.

Response: Thank you for this observation. In Figure 2, the light and dark colors indicate the P fertilizer rates on treated cropland and all cropland, respectively, both starting from zero on the y-axis and they are not cumulative stacked bars. To avoid any misunderstanding, we have clarified the interpretation of the bar plot in the figure captions. Please refer to lines 556-558.

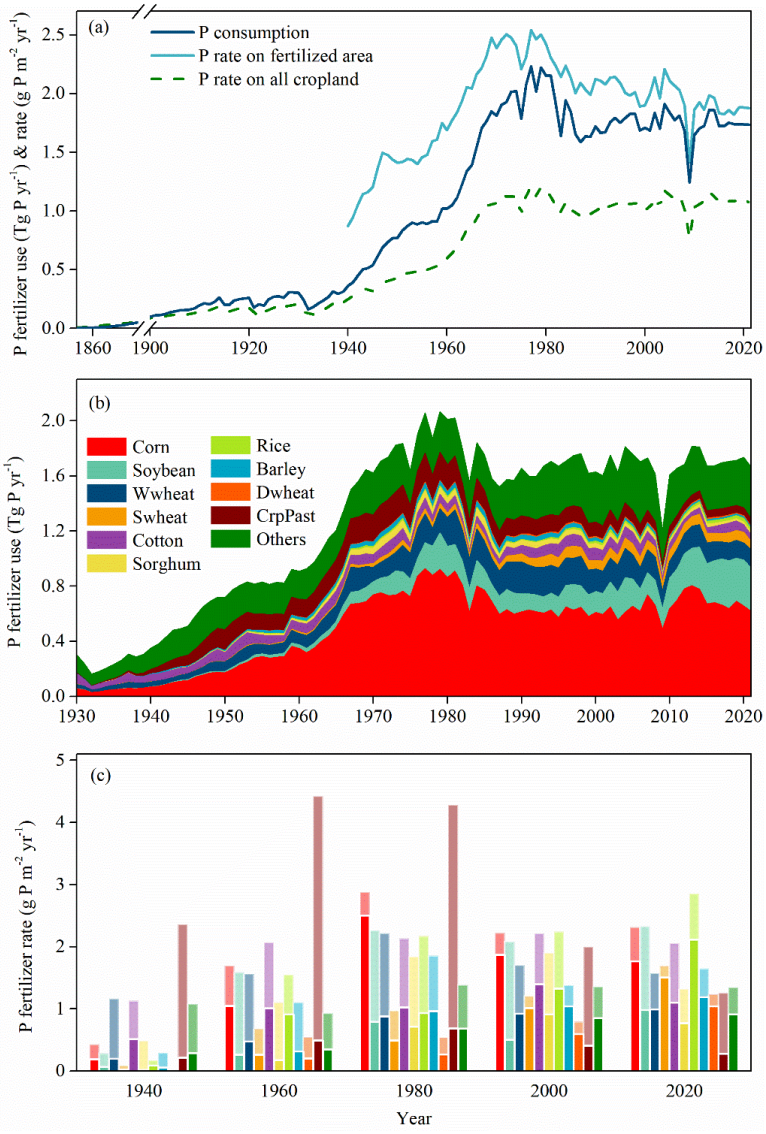
Lines 556-558: "In panel (c), light-colored bars denote the application rate on fertilized area and dark-colored bars show the modified application rate with the assumption that the county-level P fertilizer consumption was distributed on all the croplands. Both start from zero on the y-axis."

I suggested the spatial distribution of P fertilizer application rates change to the total P consumption per grid.

Response: Thank you for the suggestion. After careful consideration, we have decided to continue representing our final map using the P fertilizer rate rather than total consumption in each grid for the following reasons: 1) Our P fertilizer application rate maps represent the rate on land area rather than cropland per grid. Therefore, the total P consumption can be obtained by multiplying our P rate maps with gridded area. Please see our response to reviewer #1. We are using the 'Albers Conical Equal Area' coordinate system in spatialization, in which each grid has the same land area (16 km^2), so converting P fertilizer rate into P fertilizer consumption does not alter the spatial pattern of our final map; 2) Information on total consumption for each state and county is already available in our tabular dataset (https://doi.org/10.5281/zenodo.10700822).

Can you add the country level of P fertilizer consumption and 9 major crops from 1950 to 2022.

Response: We appreciate this good suggestion. we have included the P fertilizer consumption data for all nine major crops and Other crop from 1930 to 2022 in Figure 2.



I suggest the unit P application rate should be changed to "kg P/ha".

Response: Thank you for your suggestion to change the unit of P application rate to "kg P/ha." The suggested unit is more common in agronomy, especially for N application rate. However, after careful consideration, we have decided to retain the original unit of "g P/m^2." The g P/m^2 unit is metric-based and is more commonly used in ecological and environmental studies, facilitating detailed analysis at smaller scales. This metric unit is particularly beneficial for comparing results across diverse studies and regions, enhancing the granularity and applicability

of our findings. We believe that maintaining this unit will provide clarity and consistency with existing literature.

There are some small errors in your manuscript as follows: - Line 224, conversely should be "Conversely"- 3.2 Patterns of P fertilizer application methods should be 3.3

Response: Thank you for pointing out this. We have corrected all the typos in our manuscript.