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Supplementary information

Countries influence the trade-off between crop yields and nitrogen pollution

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Supplementary Materials for

Countries Influence the Trade-Off between Crop Yields and Nitrogen Pollution

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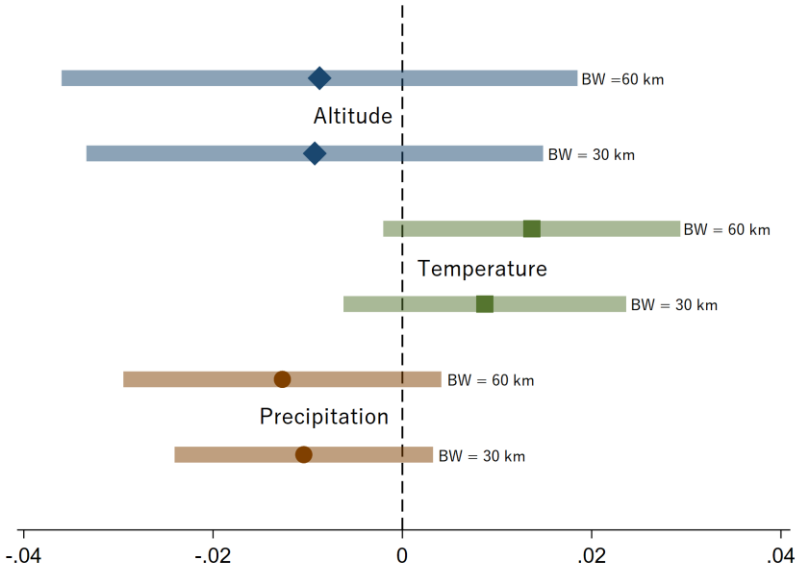
This PDF file includes:

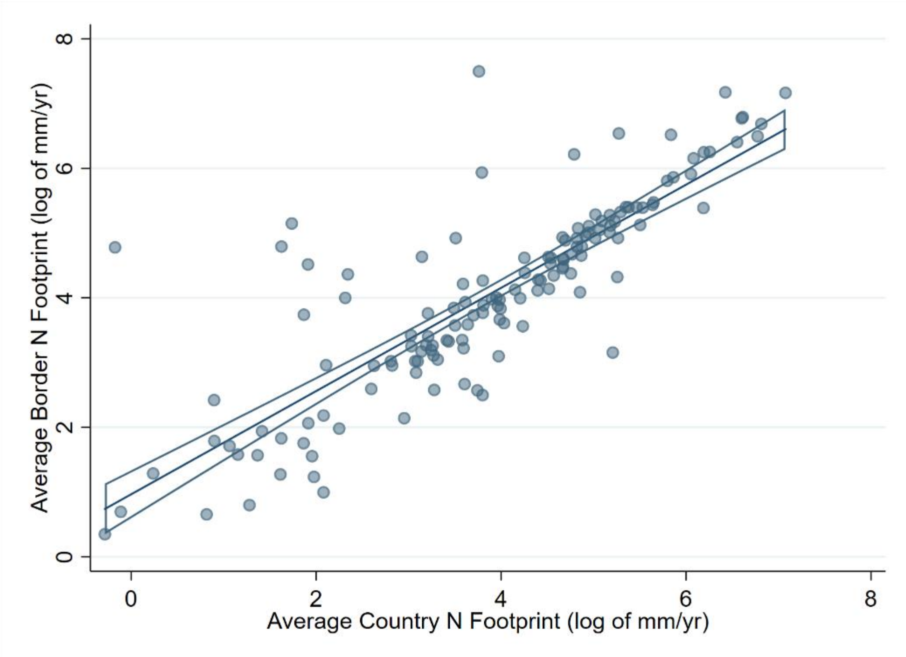
Fig. S1 to S6 and a discussion of our main explanatory variables and their data sources

Supplementary Materials for Wuepper, et al. [1]. All Data and Code can be retrieved from Wuepper, et al. [2] and from the corresponding author upon reasonable request

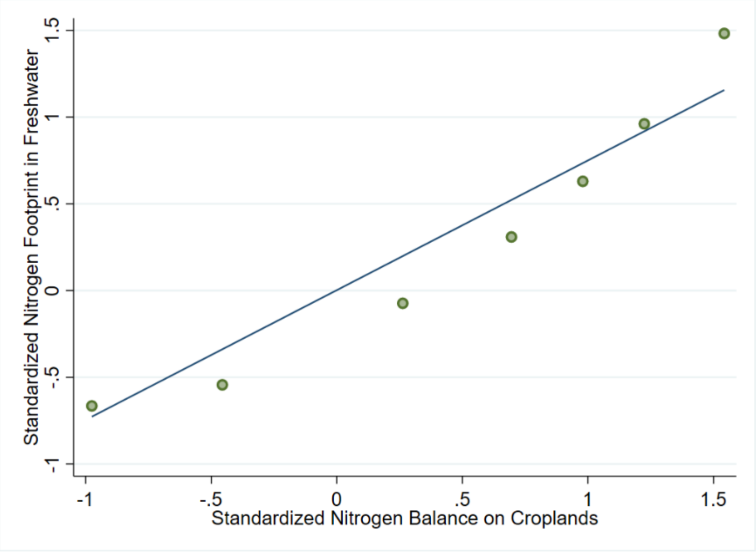
Section S1. Supplementary Figures



Supplementary Figure 1. Testing for Environmental Border Discontinuities. There are no statistically significant environmental border discontinuities, on average, between the countries. Diamonds, squares, and circles indicate the point estimates, the bars in blue, green, and brown show the 95 % confidence intervals, all of which range from positive upper bounds to negative lower bounds.

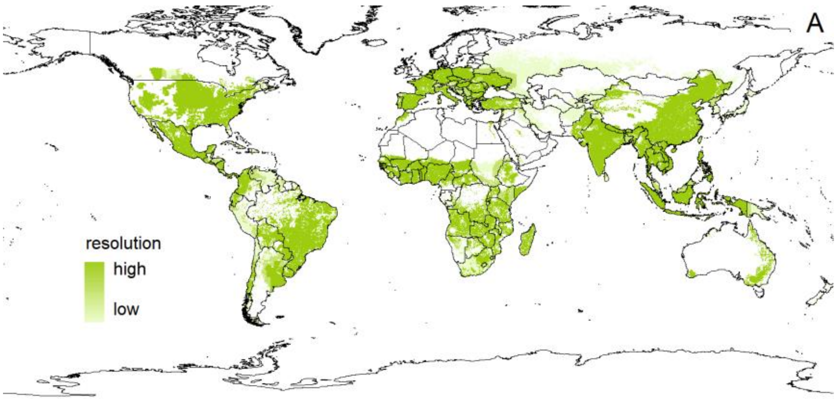


Supplementary Figure 2. Comparing Water Pollution in Border Areas and Country Averages. For our analysis, we focus exclusively on international border areas, because the areas just left and right of a border are more likely to be comparable environmentally and geographically than the areas further inland. Whether we can interpret our results as extrapolatable to the rest of the countries depends on how closely related are nitrogen water pollution in border areas and further inland. The graph above correlates country averages (x-axis) with border averages (y-axis). We see a strong positive relationship, suggesting that our findings in border areas are probably relevant beyond our sample.

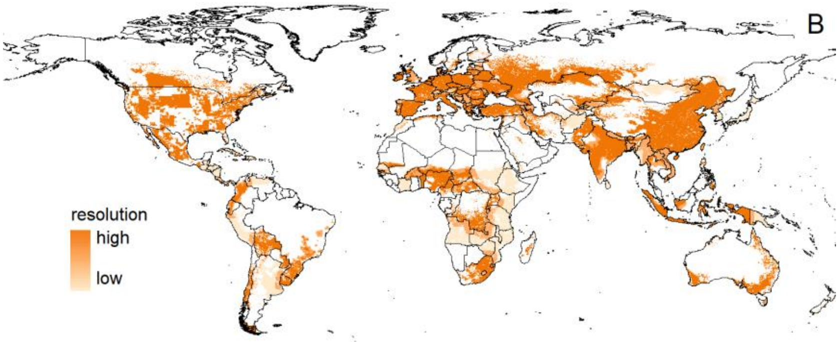


Supplementary Figure 3. Comparing Nitrogen Pollution in Water and Nitrogen Balances on Cropland. We are most concerned about nitrogen pollution in water, but not all nitrogen pollution in water comes from croplands. Here, however, we show that nitrogen pollution in freshwater (y-axis) and nitrogen balances on croplands (x-axis) are closely related. All observations are averaged in small bins (green) and their relationship is approximated with a linear regression line (blue).

The maps in **Supplementary Figure 4** below show two-resolutions of the yield data from Monfreda, et al. [3], once for maize (**a**), and once for potatoes (**b**), as examples. The yield data is used both for the modelling yield gaps and nitrogen pollution and, as can be seen below, the resolution of the data is distributed heterogeneously around the word. Above, we tested whether this influences our estimates and found that it does not. For these tests, we used the data shown in the maps below and that for all other crops that we used to compute local average yield gaps and once included this as a control variable in the baseline specification, and once excluded the countries with the lowest resolution (bottom 25%).



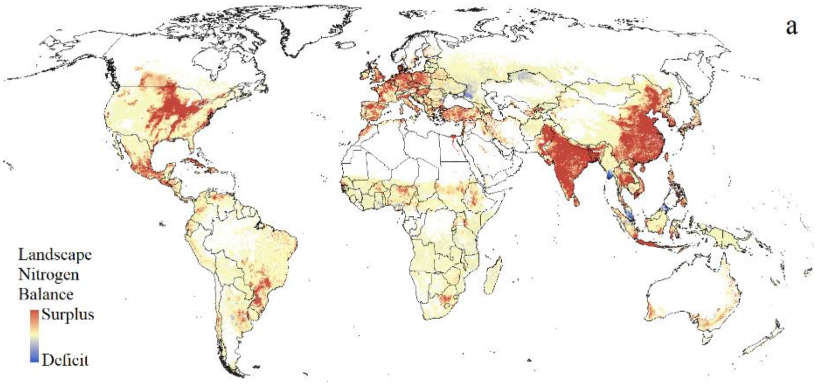
Maize

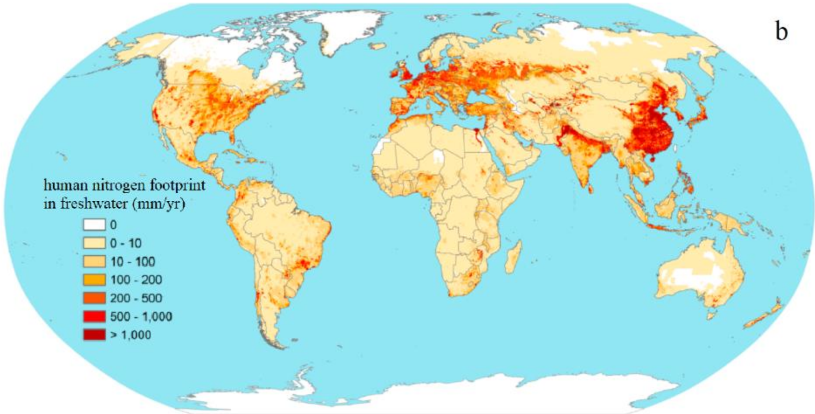


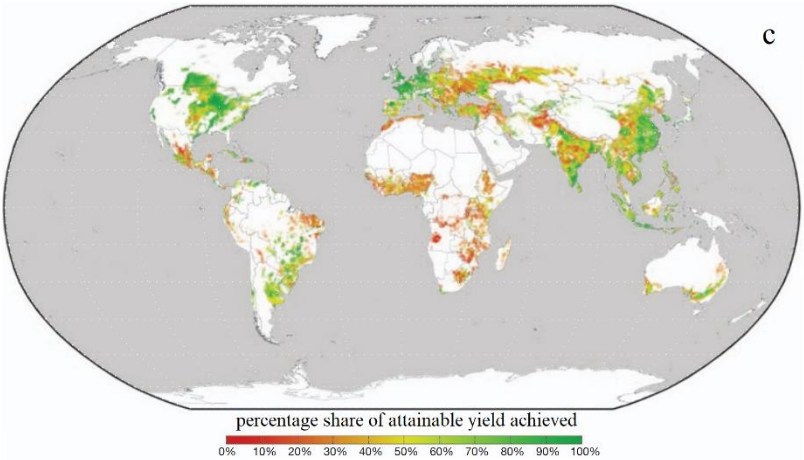
Potato

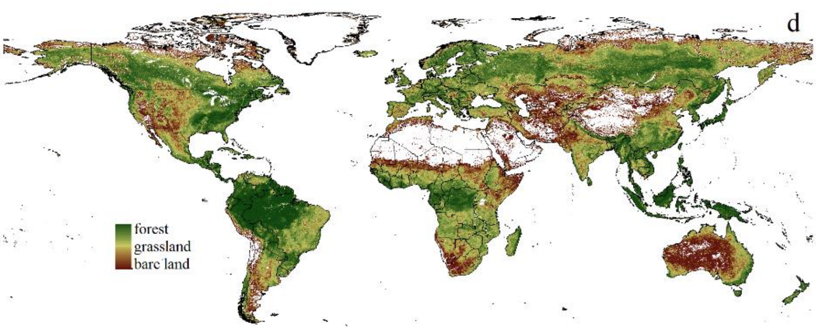
Supplementary Figure 4. Maps of Exemplary Yield Data Resolutions. Maize and Potatoes

The maps in **Supplementary Figure 5** show the global distributions of nitrogen balances on croplands[4] (**a**), water pollution[5] (**b**), attained yield as percentage of attainable[6] (**c**), and the predicted natural vegetation we would see without human impact[7] (**d**).

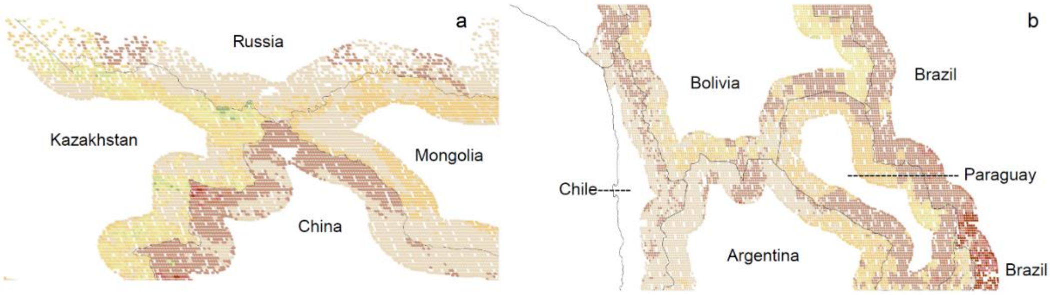








Supplementary Figure 5. Nitrogen Balances and Pollution, Crop Yields, and Hypothetical Natural Vegetation. The maps a to d show the global distributions of our main input data.



Supplementary Figure 6. By Analyzing Data Close to International Borders Only, We can Reduce the Impact of Environmental Influences. Shown here is the nitrogen balance on agricultural lands close to international borders in Asia and Latin America. Darker reds reflect larger nitrogen surpluses while darker greens reflect larger nitrogen deficits. The closer together the observations, the more similar are topography, weather, soils, and other confounders that are not caused by the countries. Still, comparing e.g. the land just in China with that just in Mongolia, or land just in Brazil with that just in Bolivia, there are apparent differences that reveal the influence of the countries.

Section S2. Data for the Exploration of Explanations

For our examination of what explains the global variation in countries' nitrogen pollution per yield, we require data on various country characteristics that relate directly or indirectly to farmers' incentives and constraints, what to grow where and how. First of all, we use data on countries gross domestic product, their value added in agriculture as percentage of gross domestic product, and their populations, all from the World Bank [8]. Previous studies have found that yield gaps close with increasing development[4,6] whereas nitrogen pollution first increases up to a point and then decreases[9,10]. However, most countries in the world are still on the increasing part of the curve and overall, richer countries cause more nitrogen pollution than poorer countries[9,10]. For population size and growth, the literature suggests lower yield gaps and more nitrogen pollution. From a policy point of view highly relevant, we also examine the role of institutional quality. The data comes from Kunčič [11]. The influence of institutional quality is ambiguous ex ante. Agricultural productivity is clearly positively associated with better institutions [12,13]. On the other hand, the effect on nitrogen pollution could be positive, if they mostly increase fertilizer use, or negative, if they also improve regulatory frameworks and environmental policies [14].

Then, we use data from the United Nations Food and Agriculture Organization - FAO [15] – on global development flows towards land resources. Previous studies have shown that financial flows can have large effects on agricultural and environmental outcomes[16]. However, again the sign is not clear again ex-ante, because less financial constraints are empirically associated both with more fertilizer input and higher yields[17]. We also use data on countries' agricultural intensity, as measured by fertilizer use, with data from FAO [15]. Higher agricultural intensity is both associated with higher yields and more pollution and overall, this should be strongly associated with more pollution per yield, given the prior literature and our own empirical evidence in this study.

Finally, two especially interesting and policy-relevant variables are countries' availability and affordability of food, provided by Chaudhary, et al. [18]. Thinking about the trade-off between yield gaps and nitrogen pollution as quantifying how much countries "buy" higher yields with environmental damage, a natural question is whether perhaps more available and affordable food for all is a benefit of lowering the costs of agricultural production by externalizing costs to the environment.

Supplementary References

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