A revised planetary boundary for agricultural nitrogen inputs

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Abstract

Nitrogen is an essential nutrient in food production but also causes major environmental problems. We present the first spatially explicit estimation of global-scale agricultural nitrogen inputs that comply with three environmental standards, i.e. critical nitrogen deposition levels in terrestrial ecosystems, and critical nitrogen concentrations in surface water and in groundwater. To meet these standards, agricultural nitrogen inputs need to decrease on two-thirds of global agricultural land, but can increase on one third. The global average critical nitrogen input is 54 kg N ha^{-1} yr^{-1}, or 132 Tg N yr^{-1}, which is 43% lower than current inputs (232 Tg N yr^{-1}).

Keywords: nitrogen, planetary boundary, surface water quality, groundwater quality, deposition, biodiversity, fertilizer, manure

1. Spatially explicit calculation of critical nitrogen inputs to agriculture

The most recent quantification of a planetary boundary for human nitrogen (N) fixation by Steffen et al. (2015) suggested that current nitrogen inputs are double the safe limit. However, their assessment did not explicitly consider the uneven distribution of agricultural nitrogen inputs, losses, and related impacts.

We used the integrated assessment model IMAGE to calculate agricultural nitrogen inputs (sum of inputs from fertilizer, manure, biological N fixation and atmospheric deposition) that comply with three environmental thresholds for each 0.5x0.5° grid cell. Thresholds relate to critical values for (i) nitrogen deposition rates (to avoid or limit terrestrial biodiversity loss), (ii) nitrogen concentrations in surface water (to limit eutrophication) and (iii) nitrogen concentrations in groundwater (drinking water standards). We calculated the allowable nitrogen inputs from fertilizer and manure, assuming that inputs from biological fixation are constant and that inputs from deposition are a function of manure and fertilizer inputs. We further assumed that non-agricultural anthropogenic nitrogen inputs (e.g. NO_x emissions from transport and industry, nitrogen load to surface water from wastewater and erosion) remain unchanged. The critical application limit for agriculture is thus determined by the sensitivity of the ecosystem (acceptable losses), the properties of the agricultural system (e.g. yields, nitrogen use efficiency), and nitrogen contamination by non-agricultural sources.

2. Results

To avoid exceeding thresholds for all three impacts, nitrogen inputs need to decrease on 62% of all agricultural land, especially in Western Europe, China, India and the US (see Fig. 1), while, nitrogen inputs can safely increase on 33% of agricultural land. Compared to current global N inputs (232

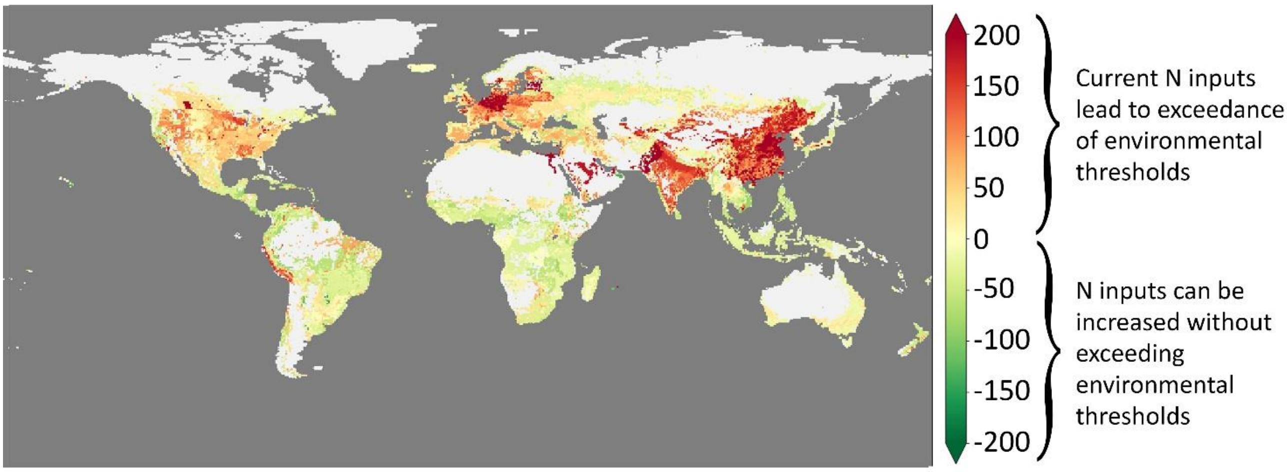

Fig. 1: Exceedance of critical nitrogen (N) inputs to agriculture in view of three environmental impacts (critical N deposition and critical N concentrations in surface water and groundwater) by current N inputs (kg N ha^{-1} yr^{-1}).

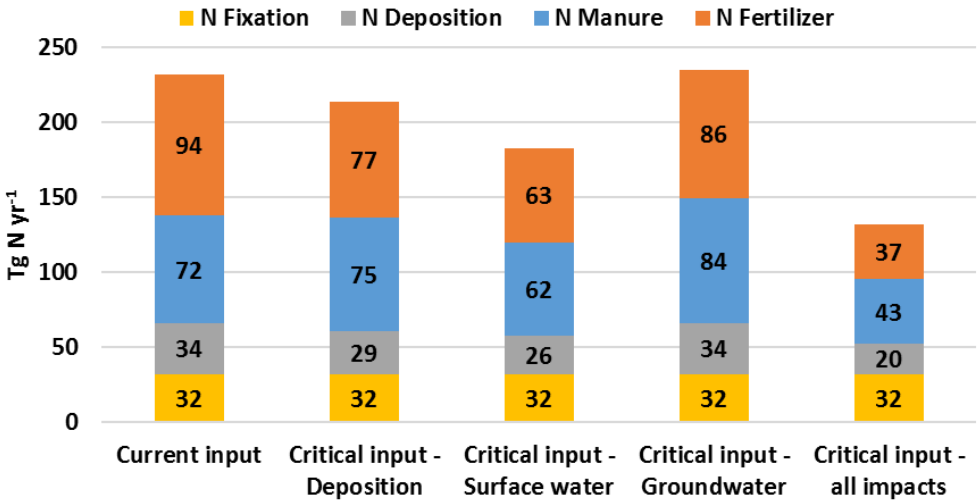

Fig. 2: Current nitrogen inputs to agriculture by source, and critical nitrogen inputs for each of the three considered environmental impacts and the minimum critical inputs related to all three impacts (Tg N yr^{-1}).

Tg N yr^{-1}), the critical N input is 1% higher for the groundwater criterion, 8% lower for the deposition criterion, 21% lower for the surface water criterion, and 43% for the minimum critical N input of all three impacts (Fig. 2). In 47% of all agricultural land, critical N inputs are determined by the surface water standard, followed by those for deposition (44%) and groundwater (9%).

3. Discussion

Our new 'planetary boundary' for agricultural N inputs (132 Tg N yr^{-1}) is about 43% lower than current N inputs, which is lower than the needed reduction of 59% to stay within safe planetary boundaries proposed by Steffen et al. (2015). Critical N inputs from fertilizer and manure account for 80 Tg N yr^{-1}.

Our calculation assumes that agriculture has to carry the full burden of complying with planetary boundaries for anthropogenic N fixation, and also show that for many regions, only reducing agricultural inputs is not sufficient.

References

Steffen W., Richardson K., Rockstrom J., Cornell S. E., Fetzer I., Bennett E. M., … Sorlin S. (2015). Planetary boundaries: Guiding human development on a changing planet. ***Science***: 1259855.