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Interactive comment on "Increased nitrogen enrichment and shifted patterns in the world's grassland: 1860–2014" *by* Rongting Xu et al.

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Dear reviewer #2,

We thanks for the precious comments and constructive suggestions. These comments were addressed in detail and incorporated into the revised manuscript and supplementary material. All changes have been marked in "blue" to be tractable in the revised manuscript.

1. To complement Figure 3 it would be nice another figure with the evolution of total surface of grasslands and also split into pasturelands and rangelands.

Response: Another figure with the evolution of total surface of grasslands, as well as the separated pastures and rangelands, has been added into the manuscript, as shown

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in Fig. S2.

2. Figure 5 should be completed with an equivalent extra figure (3 panels) including the inputs per ha in order to see the evolution of the intensification. An uncertainty that for me is very important and it is not clearly highlighted is that inside a grassland cell we have pasture and rangelands with different livestock density and for sure different deposition rates. The final manure N deposition would be highly affected by the proportion of each type of management in the cell. Disentangling this point is relevant and, in my opinion, it is an important task for further research. Authors could remark this need for the future.

Response: We have added extra three figures including the inputs per ha into the manuscript, as shown in Figs. 5d-f. We also have added two tables (Tables S2 & S3) and another figure (Fig. S3) in Supplementary Material to show the changes of pasture and rangeland areas, and average N input rates in regional pastures and rangelands over the study period, respectively. We have also analyzed N input rates at regional scales and added them in section 3 of the main text. Line 239-243 “The average synthetic N application rate in Oceania, North America, and southern Asia showed a rapid increase over the period 1961-2016 (Fig. 5d). Africa and northern Asia showed a slight increase in average N fertilizer application rates during the study period. Europe exhibited a rapid increase of N fertilizer application rates since 1961, then decreased after 2000, and then started to increase in recent five years (Fig. S3).”

Line 272-277 “The regional average manure N application rate was increasing in southern Asia and Africa during 1860-2016 (Fig. S3b). South America, Oceania, and North America exhibited a rapid decreasing trend of manure N application rates from the 1860s to the 1960s and showed continuous increases afterward until 2016 (Figs. 5e, S3b), which was associated with the substantial expansion of pasture areas (Table S2). Europe exhibited a rapid increase of manure N application rates since the 1860s, then decreased after the 1980s (Figs. 5e).”

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Line 306-313 “Oceania showed a continuously decreasing trend of average manure N deposition rates in pastures and rangelands over the period 1860-2016. Manure N deposition rates in South America decreased between 1860 and 1960 and then increased afterward until 2016 (Fig. S3c). The significant contrast of changes in manure N deposition rates in Oceania and South America between the 1860s and the 1960s is due to the substantial and rapid increase of grassland areas (Tables S2, S3). Africa and southern Asia saw continuous increases in manure N deposition rates from 1860 to 2016, whereas Europe and North America was found with decreasing deposition rates since the 1980s (Figs. 5f, S3c).” As shown in these figures, manure N application and deposition rates changed significantly associated with pasture and rangeland areas. Regions such as Oceania and South America experienced a substantial increase of pasture and rangeland areas, as described in Supplementary Material Text 2 (Table S2, S3). Due to this significant expansion, the manure N application and deposition rates are extremely high in the 1860s and decreased rapidly until the 1960s.

We totally agree with the reviewer and have already remarked your suggestions in section 4.5: “Last, inside each relevant land use cell pastures and rangelands may be characterized by different livestock density and deposition rates, which is not considered in our current datasets. The final manure N deposition would be highly affected by the proportion of each type of management in the cell. Thus, it is necessary to consider these in the future research.”

Other comments: 1. In the abstract, please clarify “manure deposition by grazing animals”, I am very used to prepare N soil budgets were the term “deposition” is used for atmospheric deposition and this clarification will improve the reading at a first sight.

Response: We have clarify it in the abstract: “We developed three global gridded datasets at a resolution of 0.5 degree by 0.5 degree for the period 1860-2016 (i.e., annual manure N deposition (by grazing animals) rate, synthetic N fertilizer use rate, and manure N application rate) by combining annual and 5-arc minute spatial data on pasture and rangeland with country-level statistics on livestock manure, mineral and chemical fertilizers, and land use information for cropland and permanent meadows and pastures."

2. Please, along the paper when you cite several papers, the order should be chronological (in the references section alphabetical).

Response: We have checked the ESSD manuscript preparation guide, which shows "In terms of in-text citations, the order can be based on relevance, as well as chronological or alphabetical listing, depending on the author's preference." Thus, we still keep our citation orders in the main text.

3. L38 not only air but also nitrate leaching to water bodies.

Response: We have added it in the main text, as shown in lines 34-39, "There is a growing recognition that livestock production is linked to increasing global greenhouse gas (GHGs) and ammonia emissions (Tubiello et al., 2018; Xu et al., 2018). Unsustainable practices, especially in intensive systems, may lead to severe pollution of aquatic systems and soil degradation locally, regional and globally, in particular through nitrate leaching to water bodies (Dangal et al., 2017; Davis et al., 2015; Fowler et al., 2013; Yang et al., 2016)."

4. L48 not only meat but also dairy products (e.g. Bai et al. 2018 Global Change Biol).

Response: We have added it in the main text, as shown in lines 50-53, "Increased meat and dairy products consumption worldwide was a major driver behind the documented increase in cattle herds globally (FAOSTAT, 2018), and thus a major cause in the observed atmospheric increase of N2O and CH4 over the past several decades (Bai et al., 2018; Bouwman et al., 2013; Dangal et al., 2017; Tubiello, 2018)."

5. L67 I am conscious that this dataset was probably developed for GHGs estimation but it will be useful for a wider audience (nutrient budgets in agricultural systems including ammonia emissions, leaching. . .).

Response: We have added it in the main text, as shown in lines 81-83, "To enhance our understanding of the role of grassland systems on the overall global GHG balance and nutrient budgets (e.g., ammonia emissions, nitrate leaching), global biogeochemistry models require spatially explicit estimates of N inputs."

6. L93 In supplements please include a table including the countries per region.

Response: We have added Table S1.

7. L138-140 To help the reader please explain briefly the FAOSTAT methodology to estimate "manure applied to soils". Is NH3 emission discounted? Is manure dumped into the rivers discounted? (e.g. China, see Gu et al. 2015 PNAS).

Response: We have added the brief description in the main text, as shown in lines 139-140, "Following IPCC guidelines, the data in this domain do not consider N leaching during treatment (FAOSTAT, 2018)."

8. In the results section please maintain the same order as in methods (i.e. manure deposition before application, or the other way around but consistently).

Response: We have changed the order in methods to maintain the same order as in results.

9. For the 3 inputs you provide the 5 top countries in terms of total input, I recommend to do the same with the input/ha to detect countries with a generalized high level of intensification.

Response: As we described above, we have analyzed N input rates at regional scales (Figs. 5d-f and S3a-c). As shown in these figures, manure N application and deposition rates changed significantly associated with pasture and rangeland areas (Tables S2 &S3). Due to this significant expansion, the manure N application and deposition rates are extremely high in the 1860s and decreased rapidly until the 1960s. The same changing patterns were found in some countries, especially within these two regions. We plot manure and synthetic N fertilizer input rates (kg N ha-1) for each country. Overall, an intensification of manure N application/deposition rates were seen in most countries, however, the degree of intensification varied significantly. Manure N deposition rates exhibit a significant wide range, averagely from 0.2 kg N ha-1 in Iceland to 1178 kg N ha-1 in Bangladesh during 1961-2016. Similarly, manure N application rates averagely ranges from 0.3 kg N ha-1 in Congo to 160 kg N ha-1 in Netherlands during 1961-2016.

In terms of synthetic N fertilizer rates, although the values are the same within each country, they are also highly affected by each country's pasture areas. During 1961-2016, synthetic N fertilizer averagely ranges from less than 0.001 kg N ha-1 in several African countries (e.g., Congo, DRC) to higher than 500 kg N ha-1 in countries with extremely small amount of pasture areas but with relatively high amount of N fertilizer inputs (e.g., South Korea, Finland). Similarly, the rates are highly associated with country's pasture areas.

Manure N application/deposition and synthetic N fertilizer rates are within a large range and are highly associated with country's pasture/grassland areas. Moreover, the intensification of country average N application/deposition rates not only depends on the degree of increases in total N input amounts, but also the degree of changes (increase/decrease) in pasture/grassland areas. Thus, we thought it might be better to present country total amount of N inputs instead of input rates.

10. L281-282 Please be careful when saying "total reactive N production of 217 TgN yr-1"), important part of the manure production has an origin in the synthetic fertilizer applied to feed crops or pasturelands, therefore is the same N recirculated into the system. You could say total "resulting in a total input of 217 Tg N yr-1 and considering that it is in part recirculated" (or something similar with that message).

Response: Since we updated our datasets to 2016, numbers have been slightly changed. We have changed "total reactive N production of 217 TgN yr-1" into "resulting in a total input of 233 Tg N yr-1". Line 339-345 "During 2000-2016, the global mineral N fertilizer application to agriculture was significant, reaching 110 Tg N yr-1 in 2016, while manure N production was 123 Tg N yr-1 (FAO, 2018; FAOSTAT, 2018), resulting in a total input of 233 Tg N yr-1. Our estimate of total N inputs (synthetic N fertilizer: 7.5 Tg N yr-1; manure N application: 8.2 Tg N yr-1; manure N deposition: 78.1 Tg N yr-1) to permanent meadows and pastures (93.8 Tg N yr-1) accounted for 45% of global total N production (manure: 114.2 Tg N yr-1; synthetic N fertilizer: 96.4 Tg N yr-1) during 2000-2016."

Please also note the supplement to this comment:
https://www.earth-syst-sci-data-discuss.net/essd-2018-94/essd-2018-94-AC2-supplement.pdf

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