Supplemental Material for Spatial and temporal patterns of nutrients and their environmental impacts from the agriculture sector in India

Regional Environmental Change

Lilian Bode[1], Arthur H.W. Beusen[1, 2], Stefan C. Dekker[3], Alexander F. Bouwman[1, 2]

[1] PBL Netherlands Environmental Assessment Agency, P.O. Box 30314, 2500 GH The Hague, The Netherlands

[2] Department of Earth Sciences – Geochemistry, Faculty of Geosciences, Utrecht University, P.O. Box 80021, 3508 TA Utrecht, The Netherlands

[c] Copernicus Institute of Sustainable Development, Utrecht University, P.O. Box 80115, 3508TC Utrecht, the Netherlands

Email: lilianbode@hotmail.com; Arthur.beusen@pbl.nl; lex.bouwman@pbl.nl; S.C.Dekker@uu.nl

Table of contents

1 Methods

1.1 Collecting crop and livestock production system raw data

In this study, all years are expressed as the fiscal year of India, which runs from April to March instead of January to December. Therefore, the year 2007 represents the period April 1st 2007 to 31st March 2008.

Subnational statistical data on crop production, livestock, and fertilizer use for India was retrieved from the Indiastat database. Collecting a complete and meaningful dataset proved to be a challenge. The Indiastat dataset for the year 2007 was the most complete and recent dataset available and was therefore selected as input for the soil nutrient budget model.

The classification and naming of states and union territories of India has been, and still is, subject of change. According to the National Informatics Centre, the federal union of India comprises 27 states (ruled by state government) and 7 union territories (ruled by central government), for a total of 34 entities in 2007. However, some union territories are too small for the chosen grid scale (30 minutes x 30 minutes) of this study. Instead of losing this information, the available data of these union territories are aggregated with the data of a neighboring state. The definition of states and union territories used in this study is presented in Table S3.

Animal stocks for the ten animal categories were collected per state and union territory from the Indiastat database for the years 1992, 1997, 2003, 2007 and 2012. The following categories needed some adjustments:

- Dairy cattle; this category equals the Indiastat sum of indigenous, exotic and cross-bred female cattle that are “In Milk” or “Dry”.
- Beef cattle; this category equals the Indiastat cattle (total) minus dairy cattle.
- Buffaloes; this category equals the Indiastat sum of yaks, mithuns and buffaloes.

The total use of N and P fertilizers and the type of fertilizer product was collected per state and union territory from the Indiastat database for the years 2000 to 2010.

Crop production and area data are available in the Indiastat database for various periods of years between 1950 and 2012 for all of the 34 crop groups distinguished by FAO (Alexandratos et al., 2012), except for the following crop groups: potatoes, sweet potatoes, cassave, vegetables & melons, bananas, citrus fruit, fruit excluding melons, oilseeds not elsewhere

specified (nes) and coconuts. Table S4 shows the data sources that were selected in consultation with the Indian Agricultural Research Institute (IARI)[1] for each of the missing crop groups for the year 2007. For five crop groups, production and area data for the year 2007 where not specified or incomplete. Table S5 describes the missing data and the applied method for generating a complete and meaningful dataset for each crop group.

[1] Dr. Arti Bhatia (Principal Scientist at the Centre for Environment Science and Climate Resilient Agriculture of the Indian Agricultural Research Institute)

1.2 Preprocessing crop and livestock production system raw data

Before the collected raw data can be used as input for the soil nutrient budget model, the data need to be preprocessed as described by Bouwman et al. (2017). This chapter describes the applied preprocessing steps that were specifically required for this study with data at subnational level for India for the year 2007.

Scaling to FAOSTAT totals

An important step is scaling the crop and livestock production system raw Indiastat data to FAOSTAT national totals, equal to the method used by Bouwman et al. (2017). In their study, subnational data for the USA and China are scaled so that the national totals match the FAOSTAT data. This method allows for comparison of model results between countries and, in this study, subnational versus national.

Distribution of animal manure over the livestock production systems per state and union territory

Two livestock production systems are distinguished, i.e., pastoral systems, and mixed and landless systems. The animal populations of the ten animal categories, along with the produced manure, need to be distributed between these two systems using the “fraction intensive”. For each animal population, the fraction intensive defines the part belonging to the mixed and landless systems. The fraction of the animal population in pastoral systems is the complement (1-this fraction). The fraction intensive for the ten animal categories is determined as follows:

- Cattle: work animals are assumed to belong to mixed and landless systems; the rest of cattle to pastoral. Animal stocks for work animals were collected per state and union territory from the Indiastat database.
- Dairy: 95% of all dairy is assumed to belong to mixed and landless systems.
- Buffaloes: 95% of all buffaloes is assumed to belong to mixed and landless systems, except for yaks; they belong to pastoral systems.
- Pigs and poultry: all pigs and poultry are assumed to belong to mixed and landless systems.
- Sheep & goats: all sheep and goats are assumed to belong to pastoral systems, except for milk goats over 1 year; they belong to mixed systems. Animal stocks for milk goats over 1 year were collected per state and union territory from the Indiastat database.
- Horses, asses, mules and camels: 60% of all horses, asses, mules and camels is assumed to belong to mixed and landless systems.

Subsequently, the animal manure production is calculated by multiplying animal stocks and excretion rates (Table S6). Further details on the method of calculating the manure available for application on crop- and grassland is supplied by Bouwman et al. (2017).

Distribution of N and P fertilizer over crop production systems per state and union territory

The distribution of N and P fertilizers over the crop production systems upland crops, legumes and wetland rice needs to be specified for each state and union territory. The applied procedure is:

1. The national total use of N and P fertilizer per crop group is obtained from the FAOSTAT database.
2. The use of N and P fertilizer per state and union territory for the crop group rice is calculated by dividing the national total fertilizer use for the crop group rice (as calculated in step 1) according to the ratio of rice production per state or union territory (as specified in paragraph 1.1) divided by the total rice production.
3. The use of N and P fertilizer per state and union territory for the crop group legumes is calculated by dividing the national total fertilizer use for the crop group legumes (as calculated in step 1) according to the ratio of soybean production per state or union territory (as specified in paragraph 1.1) divided by the total soybean production.
4. The use of N and P fertilizer per state and union territory for the crop group upland crops is calculated by dividing the national total fertilizer use for the crop group upland crops according to the ratio of wheat, sugarcane and cotton production per state or union territory, divided by the total wheat, sugarcane and cotton production. In this calculation, the wheat, sugarcane and cotton production is defined as its production area multiplied by a standard N/P fertilizer consumption for each crop group: 100/30.0, 125/44.0 and 90/22.6 kg N/P_2O_5 per ha for respectively N/P fertilizer consumption for wheat, sugarcane and cotton (FAO, 2005).

Fractions of different N fertilizers per state and union territory

The fraction of total N fertilizer use needs to be indicated for 11 N fertilizer types as distinguished by the International Fertilizer Industry Association (IFA) as input for the soil nutrient budget model. The fractions of the 11 N fertilizer types consumed for the year 2007 per state and union territory are calculated from the source data extracted from the Indiastat database. The nitrogen content of the different types of N fertilizers are based on the fertilizer specifications supplied by FAO's Plant Production and Protection Division (AGP).

Crop uptake per state and union territory

As input for the soil nutrient budget model, the N and P crop uptake per state and union territory needs to be calculated for the crop production systems upland crops, legumes and wetland rice. First, the crop uptake needs to be calculated for the 34 crop groups distinguished by FAO (Alexandratos et al., 2012). The following equation is used to calculate the crop N uptake (*N uptake*$_{crop}$ in kg N per year*)*, for each of the 34 crop groups:

$$N\ uptake_{crop} = prod_{crop}\ x\ dm_{crop}\ x\ N\ content_{crop} \quad [2]$$

In this equation, *prod*$_{crop}$ represents the crop production of the crop group (kg of harvested product per year), *dm*$_{crop}$ the dry matter fraction of the harvested product (-) and *N content*$_{crop}$ the N fraction on dry matter basis of the harvested product (-). For calculating the crop P uptake (*P uptake*$_{crop}$ in kg P_2O_5 per year) the same equation is applicable, using *P*$_2$*O*$_5$ *content*$_{crop}$ instead of *N content*$_{crop}$. The values used for calculating the N and P crop uptake are equal to the values used for the national model run and are presented in Table S7. All FAO crop groups belong the crop production system upland crops, except for:

- The crop group rice, which belongs to the crop production system wetland rice.
- The crop groups pulses, soybeans and groundnut, which belong to the crop production system legumes.

Combining this information leads to the N and P crop uptake per state and union territory calculated for the crop production systems upland crops, legumes and wetland rice.

Biological nitrogen fixation per state and union territory

The major crop groups that have the capacity to fix atmospheric nitrogen are the leguminous crops, including the group of pulses, soybeans, groundnuts. The biological nitrogen fixation for leguminous crops is calculated according to a simplified version of the approach of Salvagiotti et al. (2008), in line with the model run based on national level data. Using this approach, the nitrogen fixation for a specific crop group (*Nitrogen fixation*$_{crop}$ in kg N per year) is calculated as follows (Bouwman et al., 2017):

$$Nitrogen\ fixation_{crop} = 0.6\ x\ Total\ plant\ N_{crop} \quad [3]$$

The total plant nitrogen for a specific crop group (*Total plant N*$_{crop}$ in kg N per year) can be calculated using the following equation:

$$Total\ plant\ N_{crop} = prod_{crop}\ x\ N_{seed} + \frac{(1-Hi)}{Hi}\ x\ prod_{crop}\ x\ N_{straw} + \frac{1}{Hi}\ x\ prod_{crop}\ x\ Rr\ x\ N_{root} \quad [4]$$

In this equation, $prod_{crop}$ represents the crop production (in kg of harvested product per year) of the crop group soybean, groundnut or pulses. N_{seed} equals the nitrogen content of the seeds (-), N_{straw} the nitrogen content of the straw (-) and N_{root} the nitrogen content of the root (-). The harvest index *Hi* (-) equals the ratio seed grains:aboveground biomass, the root ratio *Rr* (-) equals the ratio roots:aboveground biomass. The values of these parameters for the crop groups soybean, groundnuts and pulses are presented in Table S8 and are equal to the values used for the national model run. The total biological nitrogen fixation per state and union territory is obtained by summing the nitrogen fixation of the crop groups legumes, soy and groundnuts per state and union territory.

Crop uptake by fodder crops per state and union territory

Crop uptake of N and P by fodder crops is also included as input for the model. Since data on fodder crop production are not available for the states and union territories of India, the distribution of fodder crop production is mimicked by using the distribution of beef cattle, dairy cattle and pigs (Bouwman et al., 2017).

Crop N uptake per state and union territory for five major crop groups for all available years

As input for the analysis of temporal and spatial patterns in N and P, the crop N uptake for all available years needs to be calculated. Since a complete dataset for all years and all 34 crop groups is not available in the Indiastat database, five crop groups have been selected as follows. First, the total crop N uptake for the 34 crop groups for India, based on the FAOSTAT database, was calculated for the years 1960 to 2010 according to Equation 2, with values for dry matter and N content as given in Table S9. Subsequently, the availability of a complete dataset for the period 1960-2010 was checked in the Indiastat database for the crop groups representing more than 5% of the total crop N uptake of India according to the FAOSTAT database. The crop groups wheat, rice, soybean, groundnut and cotton met these criteria and were selected for the analysis of temporal and spatial patterns of N crop uptake for the years 1960 to 2010. The crop N uptake for each of the five crop groups per state and union territory was calculated according to Equation 2, with dry matter and N content values as given in Table S9.

1.3 IMAGE-GNM model change: subnational instead of national level data as input for the soil nutrient budget model

In IMAGE, the spatial heterogeneity within a country is not taken into account (e.g., in livestock production systems, crop production systems and fertilizer use), any behavior is average behavior at country level and major differences between regions within a country are masked. To demonstrate local variabilities that are not captured at the scale of national soil nutrient budget inventories, data at subnational level have already been used for the US and China as input for the soil nutrient budget model (Beusen et al., 2008; Bouwman et al., 2009; Bouwman et al., 2017; Bouwman et al., 2013).

This study represents the first effort of using data at subnational level as input for the soil nutrient budget model for India. Fig. S4 and Fig. S5 show the differences in spatial patterns of the calculated soil N and P budgets and NH_3 emissions, respectively, based on national and subnational level calculations. These differences are the result of differences in the spatial distribution of the N and P inputs in the soil nutrient budget model.

2 Supplementary figures

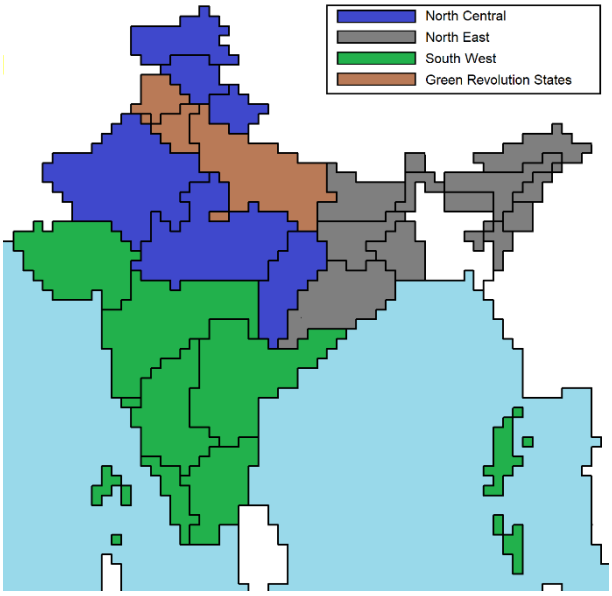
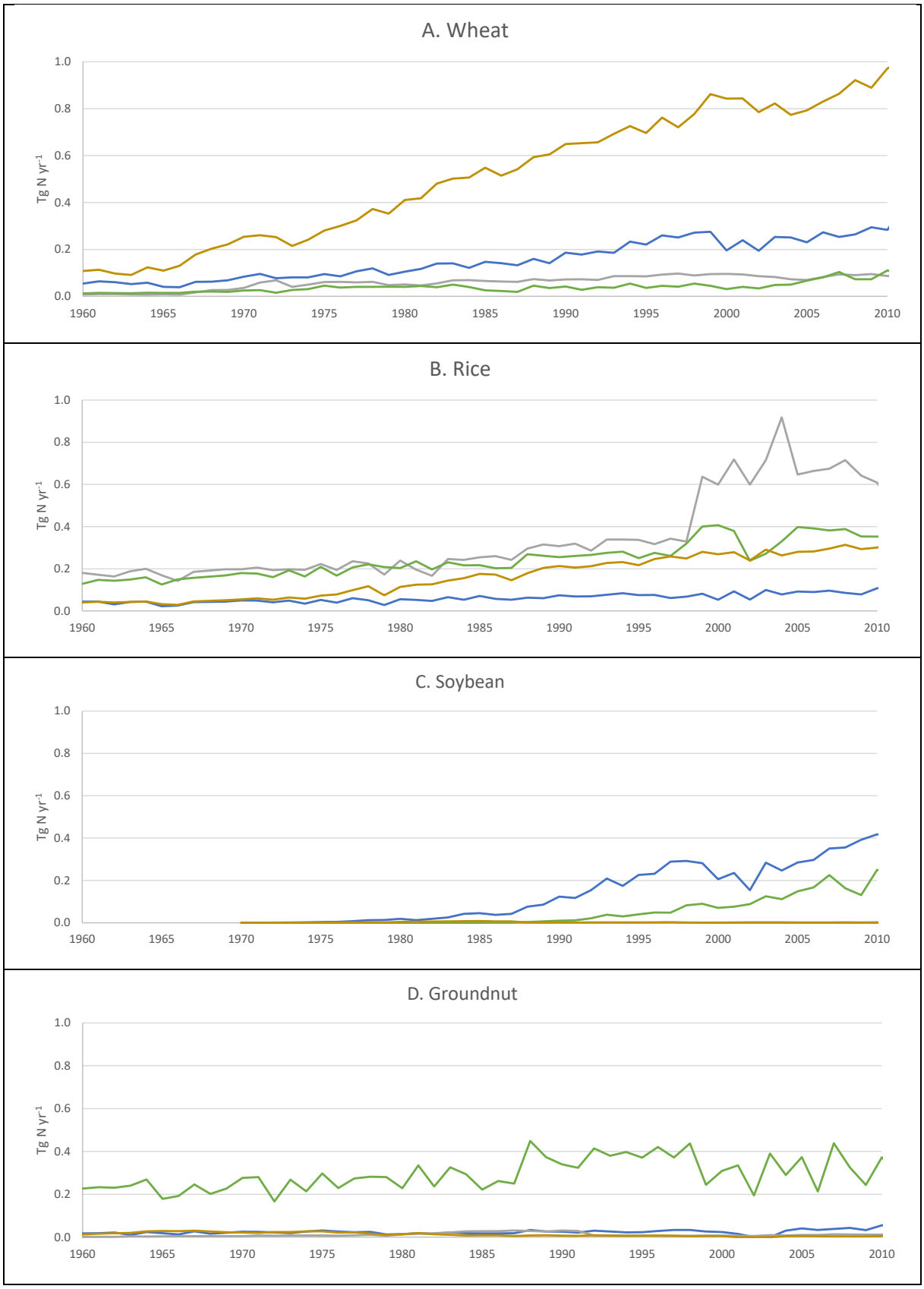


Fig. S1 Four regions of India with the North Central region in dark blue, North East in grey, South West in green and the Green Revolution States in brown. Neighboring countries are presented in white, water in light blue

.


A. Wheat
B. Rice
C. Soybean
D. Groundnut
Tg N yr-1
1.0
0.8
0.6
0.4
0.2
0.0
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

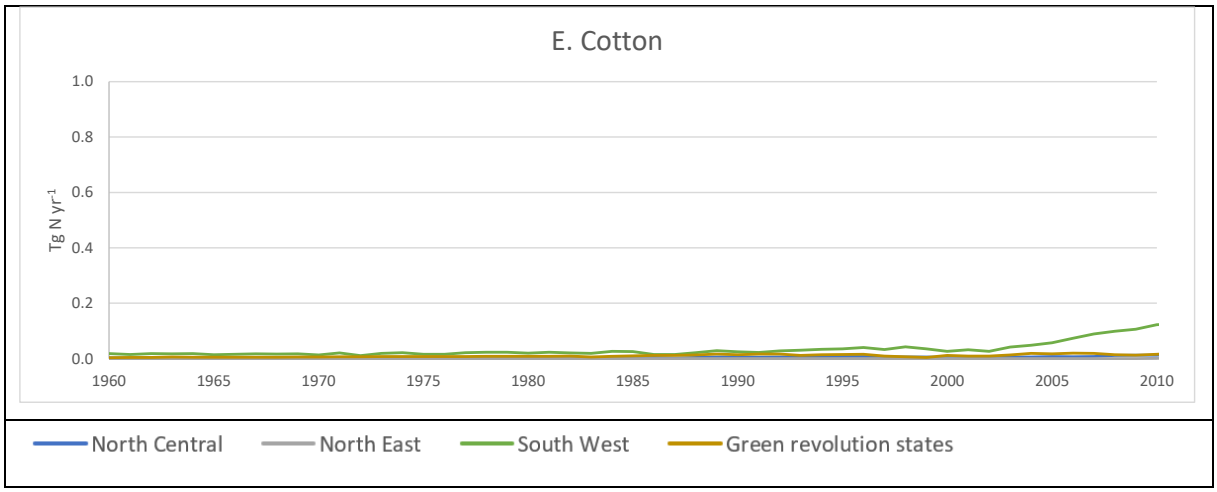


Fig. S2 Historical yearly crop uptake of five major crops wheat, rice, soybean, groundnut and cotton, for the four regions of India for the years 1960-2010, based on data from the Indiastat database

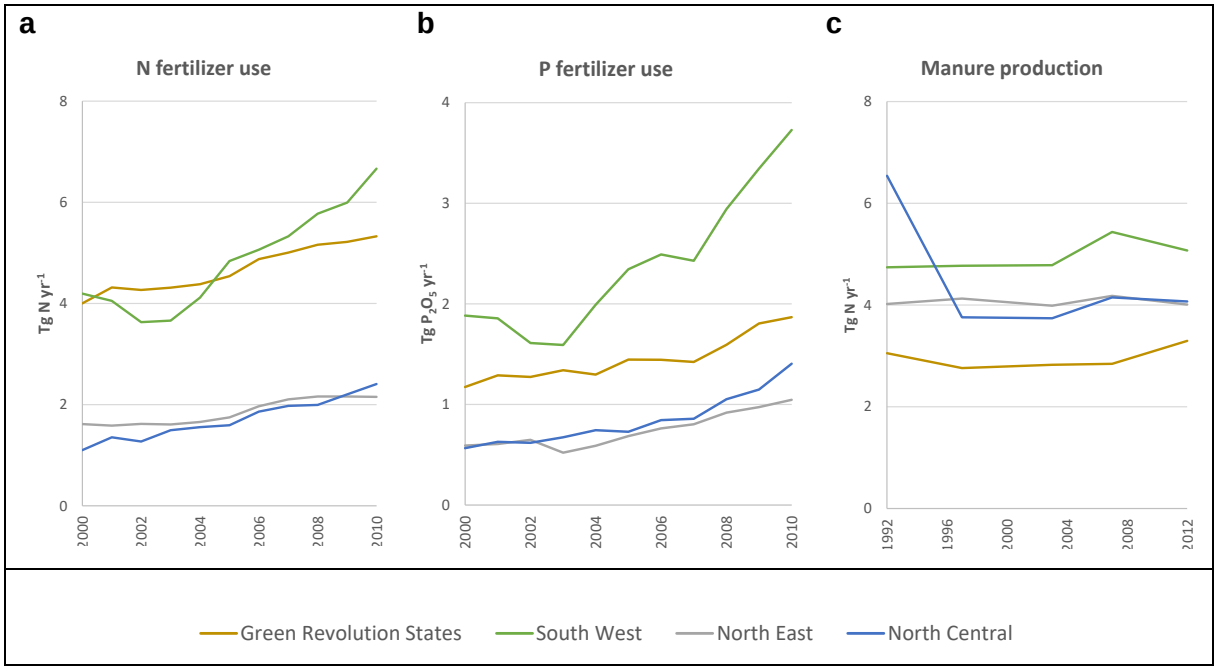


Fig. S3 Historical yearly N and P fertilizer use (years 2000-2010) and N manure production (years 1992-2012) for the four regions of India, based on data from the Indiastat database

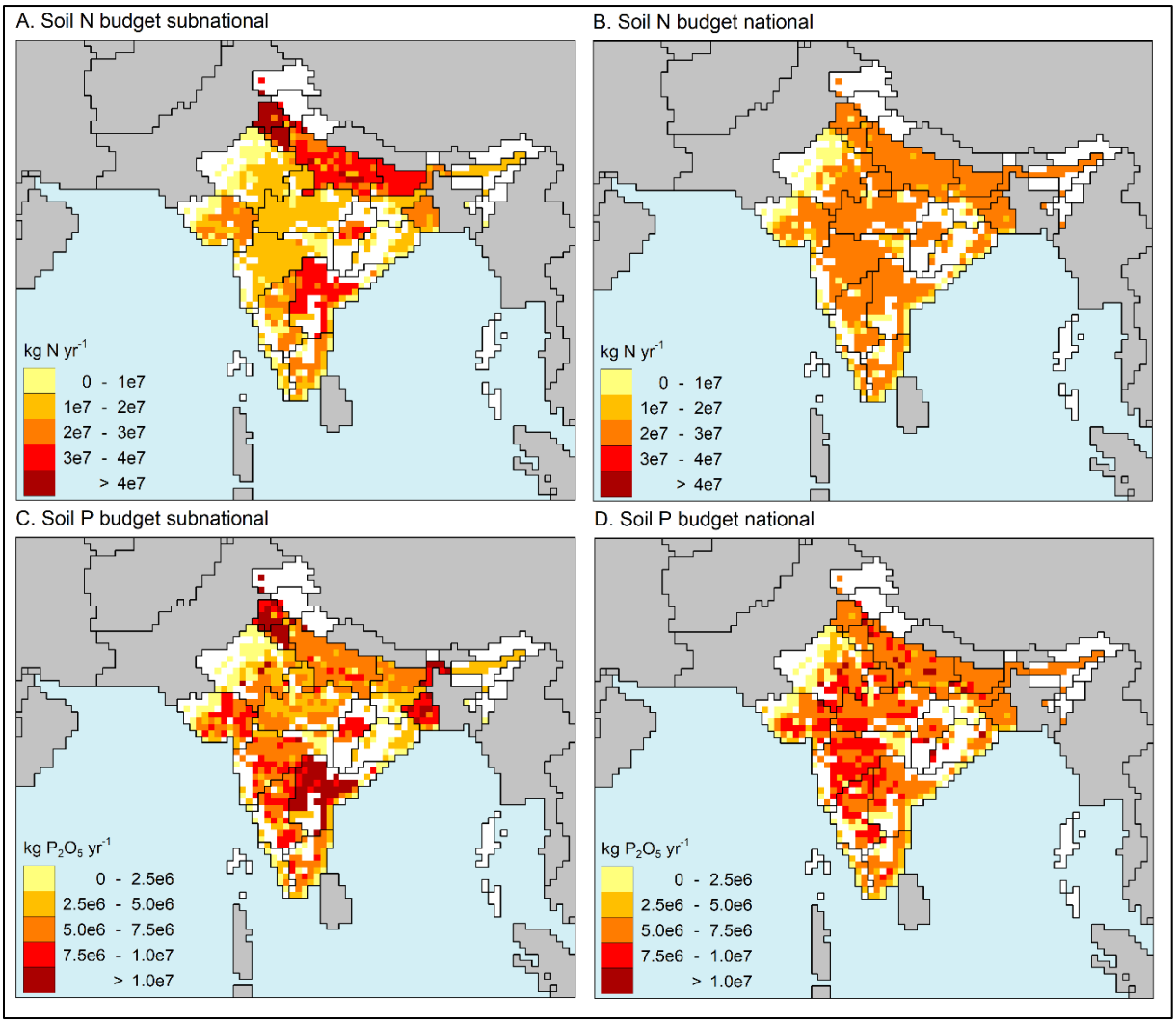


Fig. S4 Spatially explicit soil N and P budgets for the year 2007 based on data on subnational (Figures A and C) and national level (Figures B and D) as input for the soil nutrient budget model. Neighboring countries are presented in grey, water in blue, non-agricultural land in white, grid size is 30 x 30 minutes

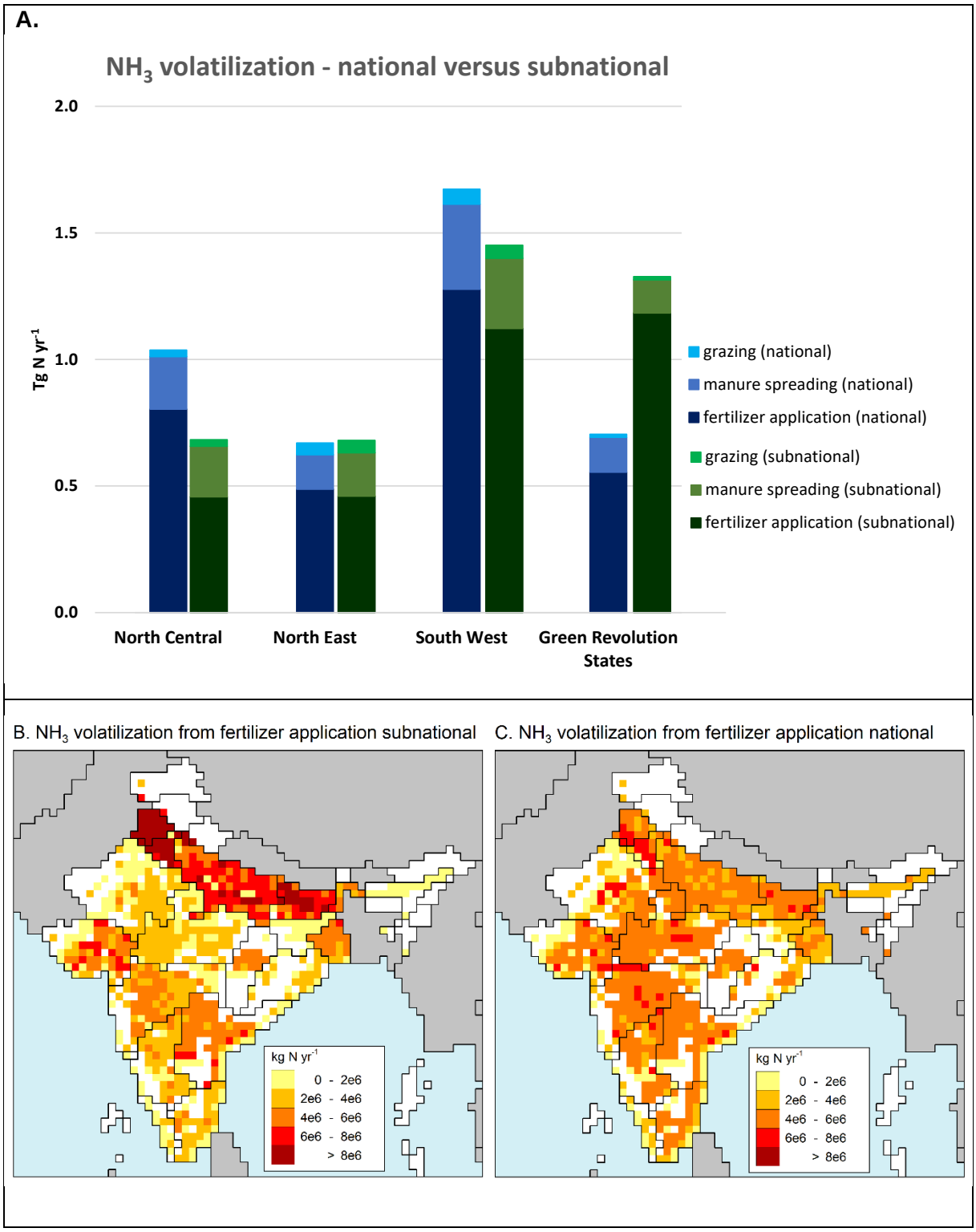


Fig. S5 NH_3 volatilization from spreading of N fertilizers, animal manure and grazing for 2007 for four regions of India at subnational (green) and national (blue) level (A) and spatially explicit NH_3 volatilization from spreading of N fertilizers based on data on subnational (B) and national (C) level for 2007 as input for the soil nutrient budget model. Neighboring countries are presented in grey, water in blue, non-agricultural land in white, grid size is 30 x 30 minutes

Fig. S6 Historical yearly N and P fertilizer use (years 2000-2010), N manure production (years 1992-2012) and crop N uptake by five major crop groups wheat, rice, soybean, groundnut and cotton (years 1960-2010) for the four regions of India represented as stacked columns, based on data from the Indiastat database. The dark blue lines represent the national total values according to the FAOSTAT database for all available years (figures a-d), the dotted dark blue line represents the value national total values for all 34 crop groups according to the FAOSTAT database for all available years (figure d)

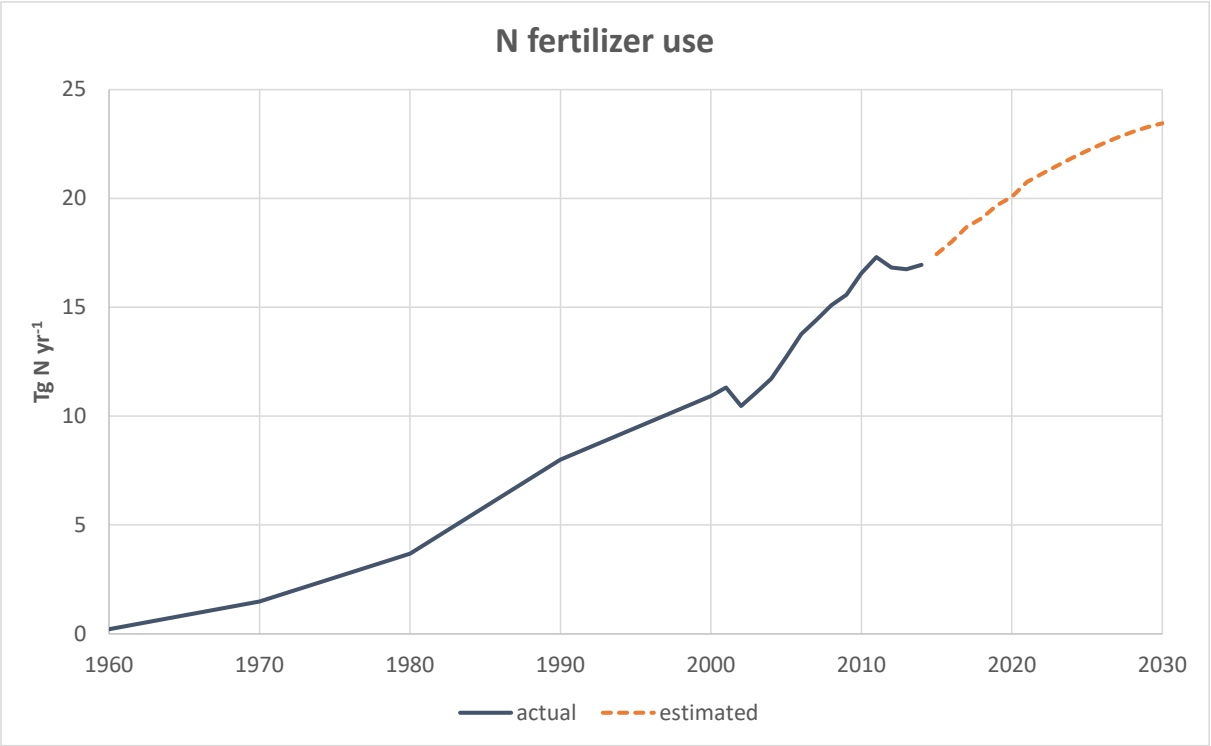


Fig. S7 Historical yearly N fertilizer use (years 1960-2014) and projected yearly N fertilizer use (years 2015-2030) for total India, based on data from the Indian Nitrogen Assessment (Abrol et al., 2017). The dark blue line represents the actual yearly N fertilizer use, the dotted orange line represents the projected N fertilizer use

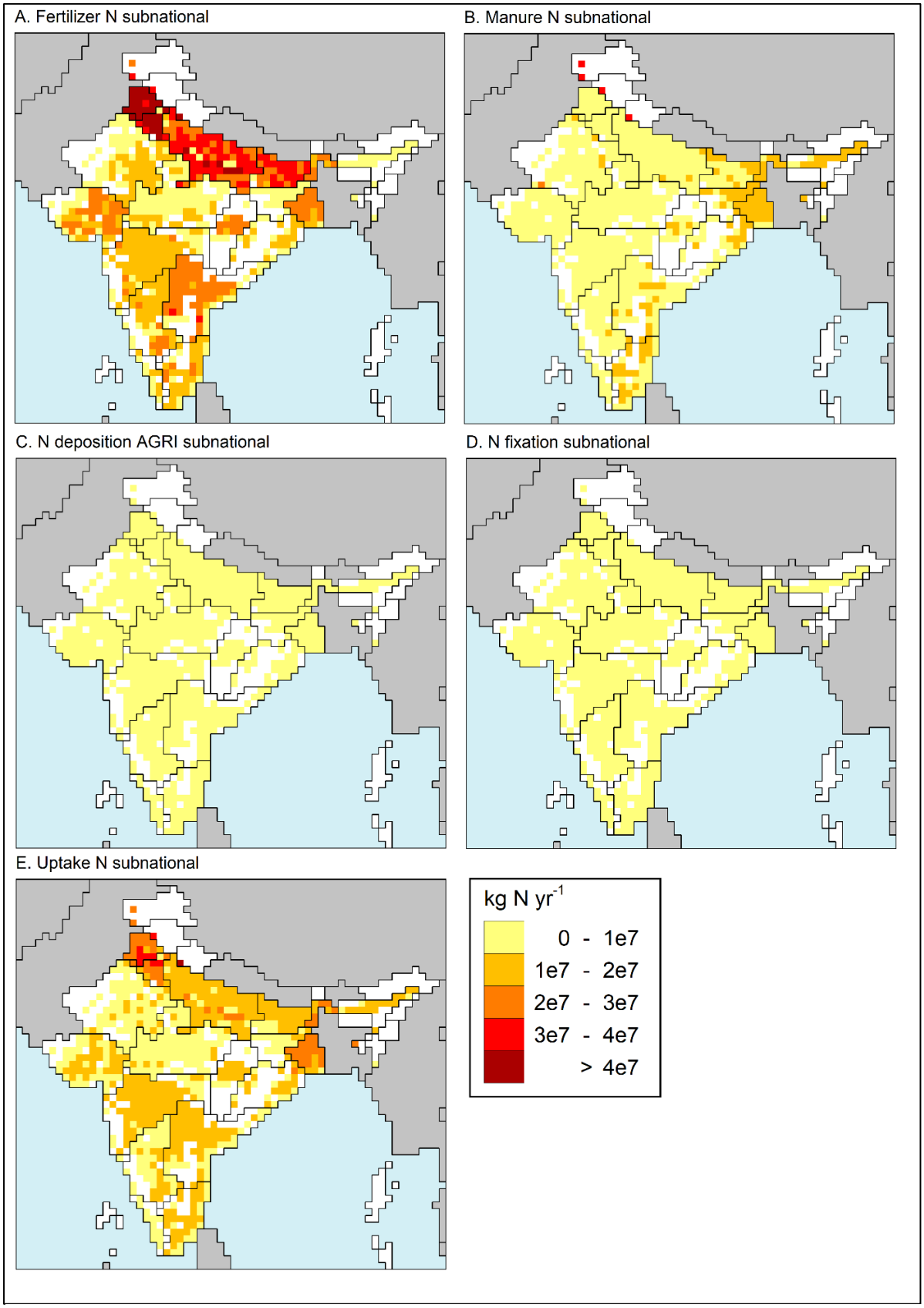


Fig. S8 Spatially explicit N inputs (Figs. A-D) and output (Fig. E) for the year 2007 based on data on subnational level as input for the soil nutrient budget model. Neighboring countries are presented in grey, water in blue, non-agricultural land in white, grid size is 30 x 30 minutes

3 Supplementary tables

Table S1. Total land area, agricultural land area and natural land area for each of the four regions of India and for total India, as used by the soil nutrient budget model for the national and subnational calculations for the year 2007.

Region	Land area (10^5 km^2)	Agricultural land area (10^5 km^2)	Natural land area (10^5 km^2)
North Central	9.9	4.6	5.3
North East	6.8	3.3	3.5
South West	11.3	7.8	3.5
Green Revolution States	3.4	3.2	0.1
Total India	31.4	19.0	12.4

Table S2. Definition of the four regions of India and corresponding states and union territories per region, as used in this study.

North Central	North East	South West	Green Revolution States
▪ Chhattisgarh ▪ Delhi ▪ Himachal Pradesh ▪ Jammu and Kashmir (& Ladakh) ▪ Madhya Pradesh ▪ Rajasthan ▪ Uttarakhand	▪ Arunachal Pradesh ▪ Assam ▪ Bihar ▪ Jharkhand ▪ Manipur ▪ Meghalaya ▪ Mizoram ▪ Nagaland ▪ Odisha ▪ Sikkim ▪ Tripura ▪ West Bengal	▪ Andaman and Nicobar Islands ▪ Andhra Pradesh (& Telangana) ▪ Goa ▪ Gujarat, Dadra & Nagar Haveli, Daman & Diu ▪ Karnataka ▪ Kerala & Lakshadweep ▪ Maharashtra ▪ Tamil Nadu & Puducherry	▪ Haryana ▪ Punjab & Chandigarh ▪ Uttar Pradesh

Table S3. Definition of states and union territories of India used in this study.

Name of state/union territory
Andaman & Nicobar Islands
Andhra Pradesh
Arunachal Pradesh
Assam
Bihar
Chhattisgarh
Delhi
Goa

Gujarat, Dadra, Nagara Haveli, Daman & Diu
Haryana
Himachal Pradesh
Jammu & Kashmir
Jharkhand
Karnataka
Kerala & Lakshadweep
Madhya Pradesh
Maharashtra
Manipur
Meghalaya
Mizoram
Nagaland
Orissa
Punjab & Chandigarh
Rajasthan
Sikkim
Tamil Nadu & Pondicherry
Tripura
Uttar Pradesh
Uttaranchal
West Bengal

Table S4. Selected sources for data on agricultural production volume and area for the missing nine crop groups.

Source	**Supplying crop data for FAO crop group:**
Indian Horticulture Database 2009, report published by the National Horticulture Board (NHB, 2010), Ministry of Agriculture, Government of India.	Potatoes, sweet potatoes, cassava (as tapioca), vegetables & melons, bananas, citrus fruit and fruit excluding melons
Status paper on oilseed crops (Singh, 2014), Directorate of Oilseeds Development, Ministry Of Agriculture, Government of India.	Oilseeds not elsewhere specified (nes): castor, niger, linseed and safflower
All India final estimates of Area and Production of Coconut (CDB), Coconut Development Board, Ministry of Agriculture and Farmers Welfare, Government of India.	Coconuts (production in “million nuts”)

Table S5. Applied method for generating a complete and meaningful dataset per applicable crop group.

FAO crop group	**Description of missing data and applied method**
Maize	Where this leads to unrealistic crop yields, for these states, from 1999 onwards, the same growth in agricultural area has been applied as registered for the other states.
Pearlmillet	From 2001 onwards, only three states have registered agricultural area and production. In the states where production and area were not equal to zero in 2000, the same growth was applied as for the three aforementioned states.
Tea	From 2003 onwards, only five states have registered agricultural area and production. In the states where production and area were not equal to zero in 2002, the same growth was applied as for the five aforementioned states.
Tobacco	Data on agricultural area and production are missing for the years 2002-2007. For the year 2007, the same year growth in area and production towards 2008 is assumed as from the year 2009 to 2010.
Rubber	Until 2010, production data per state is only registered for three states. In the states where production was not equal to zero in 2010, the same growth from 2007 to 2010 was applied as for the three aforementioned states.

Table S6. Excretion rates for the different animal categories (Bouwman et al., 2017).

Animal category	Excretion in kg N or P_2O_5 $head^{-1}$ $year^{-1}$	
	N	P_2O_5
1. Beef cattle	40	7.0
2. Dairy cattle	60	10.5
3. Buffaloes	45	7.9
4. Pigs	11	1.8
5. Poultry	0.5	0.1
6. Sheep and goats	10	1.5
7. Horses	45	6.5
8. Asses	30	4.4
9. Mules	30	4.4
10. Camels	55	8.0

Table S7. Values used for calculating the crop N and P_2O_5 uptake per state and union territory for the year 2007.

11 IMAGE crop groups	FAO crop groups	N $content_{crop}$ (-)	P_2O_5 $content_{crop}$ (-)	dm_{crop} (-)
1	Wheat, barley, other cereals (Temperate cereals)	0.021109	0.008918	0.879718334
2	Rice	0.014773	0.006507	0.88
3	Maize	0.015909	0.007548	0.88
4	Millet, sorghum, (Tropical cereals)	0.017647	0.008083	0.85
5	Pulses	0.041176	0.006736	0.85
6	Potatoes, sweet potatoes, cassava, other roots, (root & tuber crops)	0.009994	0.003737	0.261909188
7	Oilseeds nes	0.032608696	0.012447405	0.92
7	Rapeseed	0.038351648	0.014094293	0.91
7	Oil palm fruit	0.015851064	0.007553191	0.94
7	Soybeans	0.072941176	0.013472486	0.85
7	Groundnuts in shell	0.060509554	0.010211629	0.942
7	Sunflower seed	0.037173913	0.011202665	0.92
7	Sesame seed	0.035531915	0.013644475	0.94
7	Coconuts	0.002366071	0.00100994	0.896
8	Plantains, sugar beets, sugar cane, vegetables & melons, bananas, citrus fruit, fruit excl. melons, cocoa beans, coffee, tea, tobacco, seed cotton, fibre crops primary, rubber (other crops)	0.015078	0.005901	0.201054033

Table S8. Values used for calculating the biological nitrogen fixation per state and union territory for the year 2007 (Bouwman et al., 2017).

FAO crop group	Harvest index Hi (-)	N_{seed} (-)	N_{straw} (-)	N_{root} (-)	Root ratio Rr (-)
Soybean	0.5	0.062	0.015	0.015	0.19
Groundnut	0.5	0.035	0.008	0.008	0.19
Pulses	0.5	0.035	0.008	0.008	0.19

Table S9. List of the 34 crops (FAOSTAT), their N content on dry matter basis, and dry matter content of the harvested product (Bouwman et al., 2017).

Crops	Name	N content (-)	Dry matter (-)
1	Wheat	0.019	0.880
2	Rice, Paddy	0.013	0.880
3	Maize	0.014	0.880
4	Barley	0.017	0.880
5	Millet	0.015	0.850
6	Sorghum	0.015	0.850
7	Other cereals	0.016	0.870
8	Potatoes	0.003	0.212
9	Sweet Potatoes	0.003	0.272
10	Cassava	0.002	0.326
11	Other roots	0.003	0.270
12	Plantains	0.002	0.653
13	Sugar Beets	0.002	0.260
14	Sugar Cane	0.002	0.232
15	Pulses, Total	0.035	0.850
16	Vegetables & Melons, Total	0.002	0.070
17	Bananas	0.002	0.257
18	Citrus Fruit, Total	0.001	0.103
19	Fruit excl Melons, Total	0.001	0.131
20	Oilseeds nes	0.030	0.920
21	Rapeseed	0.035	0.910
22	Oil Palm Fruit	0.015	0.940
23	Soybeans	0.062	0.850
24	Groundnuts in Shell	0.057	0.942
25	Sunflower Seed	0.034	0.920
26	Sesame Seed	0.033	0.940
27	Coconuts	0.002	0.896
28	Cocoa Beans	0.014	1
29	Coffee, Green	0.024	1
30	Tea	0.078	0.525
31	Tobacco Leaves	0.003	0.210
32	Seed Cotton	0.029	0.920
33	Fibre Crops Primary	0.081	1
34	Rubber	0.000	1

Table S10. NH_3 volatilization from spreading of N fertilizers, animal manure, grazing and storage and housing for 2007 for India based on model calculations with data at subnational level.

Source of NH_3 volatilization	North Central	North East	South West	Green Revolution States	India	
	Tg N yr^{-1}	Tg N yr^{-1}	Tg N yr^{-1}	Tg N yr^{-1}	Tg N yr^{-1}	% of total
N fertilizer application	0.46	0.46	1.12	1.18	3.22	62%
Manure spreading	0.20	0.17	0.28	0.13	0.78	15%
Grazing	0.03	0.05	0.05	0.01	0.14	3%
Storage and housing	0.26	0.24	0.37	0.18	1.05	20%

4 References

Abrol, Y. P., Adhya, T., Aneja, V. P., Raghuram, N., Pathak, H., Kulshrestha, U., . . . Singh, B. (2017). *The Indian Nitrogen Assessment*. Doxfurd, Cambridge , UK: Elsevier.

AGP. Fertilizer Specifications of FAO's Plant Production and Protection Division AGP. Retrieved from http://www.fao.org/agriculture/crops/thematic-sitemap/theme/spi/plantnutrition/fertspecs/en/#c29984

Alexandratos, N., & Bruinsma, J. (2012). *World agriculture towards 2030/2050: the 2012 revision*. Retrieved from http://www.fao.org/3/a-ap106e.pdf

Beusen, A. H. W., Bouwman, A. F., Heuberger, P. S. C., Van Drecht, G., & Van Der Hoek, K. W. (2008). Bottom-up uncertainty estimates of global ammonia emissions from global agricultural production systems. *Atmospheric Environment, 42*(24), 6067-6077.

Bouwman, A. F., Beusen, A. H. W., & Billen, G. (2009). Human alteration of the global nitrogen and phosphorus soil balances for the period 1970–2050. *23*(4). doi:doi:10.1029/2009GB003576

Bouwman, A. F., Beusen, A. H. W., Lassaletta, L., van Apeldoorn, D. F., van Grinsven, H. J. M., Zhang, J., & Ittersum van, M. K. (2017). Lessons from temporal and spatial patterns in global use of N and P fertilizer on cropland. *Scientific Reports, 7*, 40366.

Bouwman, A. F., Goldewijk, K. K., Van Der Hoek, K. W., Beusen, A. H. W., Van Vuuren, D. P., Willems, J., . . . Stehfest, E. (2013). Exploring global changes in nitrogen and phosphorus cycles in agriculture induced by livestock production over the 1900–2050 period. *Proceedings of the National Academy of Sciences, 110*(52), 20882-20887.

CDB. All India final estimates of Area and Production of Coconut by the Coconut Development Board (CDB). http://coconutboard.nic.in/Statistics.aspx

FAO. (2005). *Fertilizer use by crop in India*. Retrieved from http://www.fao.org/tempref/agl/agll/docs/fertuseindia.pdf

FAOSTAT. Food and agricultural data. Retrieved May 3, 2019 http://www.fao.org/faostat/en/#home

IFA. IFADATA statistics of the International Fertilizer Industry Association. Retrieved May 3, 2019 https://www.fertilizer.org/

Indiastat. Socio-economic statistical information about India and its states. Retrieved 16 november 2018, from Datanet India https://www.indiastat.com

NHB. (2010). *Indian Horticulture Database 2009*. Retrieved from http://planningcommission.gov.in/sectors/agri_html/Indian%20Horticulture%20database-2009.pdf

Salvagiotti, F., Cassman, K. G., Specht, J. E., Walters, D. T., Weiss, A., & Dobermann, A. (2008). Nitrogen uptake, fixation and response to fertilizer N in soybeans: A review. *Field Crops Research, 108*(1), 1-13. doi:https://doi.org/10.1016/j.fcr.2008.03.001

Singh, R. P. (2014). *Statuspaper on oilseed crops*. Retrieved from http://oilseeds.dac.gov.in/StatusPaper/StatusPaper.pdf