Inventory of methane and nitrous oxide emissions from agricultural soils of India and their global warming potential

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Agricultural soils contribute towards the emission of methane and nitrous oxide, the two important greenhouse gases causing global warming. Due to the diverse soil, land-use types and climatic conditions, there are uncertainties in quantification of greenhouse gas emission from agricultural soils in India. An inventory of the emission of methane and nitrous oxide from different states in India was prepared using the methodology given by the Inter-Governmental Panel on Climate Change. For methane emission, state-specific emission coefficients have been used for all major rice ecosystems. In case of nitrous oxide, both direct and indirect emissions from agricultural soils in different states have been calculated using the emission coefficients derived from the experiments conducted in India. For the base year 1994–95, methane and nitrous oxide emissions from Indian agricultural fields were estimated to be 2.9 Tg (61 Tg CO$_2$ equivalent) and 0.08 Tg (39 Tg CO$_2$ equivalent) respectively.

INTERNATIONAL concern for rising anthropogenic greenhouse gas emission and potential dangerous consequences of global climate change has led to the establishment of the United Nations Framework Convention on Climate Change (UNFCCC), following the Earth Summit in June 1992. Most of the countries around the world, with a view to taking positive steps to reduce greenhouse gas emissions and combat climate change adopted the UNFCCC, which requires all parties to compile, periodically update and publish national inventories of greenhouse gas emission sources and sinks using comparable methodologies that have been agreed upon by the Conference of Parties (COP).

Methane (CH$_4$) and nitrous oxide (N$_2$O) are the important greenhouse gases contributing 15 and 5% respectively, of the enhanced greenhouse effect. Agricultural and associated sectors produce about 50 and 70%, respectively, of the total anthropogenic emissions of these gases$^1$. Biological generation of methane in anaerobic environment, including enteric fermentation in ruminants, flooded rice fields, and anaerobic animal waste processing, are the principal sources of methane from agriculture. The primary sink for methane is oxidation with hydroxyl radicals in the troposphere. Aerobic soils provide an additional sink of 10–20% of annual methane emissions. Agriculture sector contributed over 80% of all-India methane emissions in 1995, including 42% from livestock-related activities, 23% from rice paddy cultivation and 16% from biomass consumption$^2$.

Paddy cultivation occupies 42.24 mha in the Indian subcontinent, the largest in Asia, and is one of the major sources of methane emission. Indian rice fields are often blamed to be major contributors of atmospheric methane. According to the United States-Environment Protection Agency (US-EPA) estimate in the early nineties based on extrapolation of measurements in USA and Europe, the annual methane emission from Indian rice paddies was 37.8 Tg (Tg = 10$^{12}$ g or million tonne). This estimate was lowered to a great extent after actual measurements were carried out in India. Though the experiments have been conducted at several places, they are too few to be extrapolated to the whole of India for calculation of the methane budget. In 1991, a campaign was carried out for methane measurements across the rice-growing states in India$^3$. The data generated from this campaign assigned a methane budget of 4 Tg per annum from Indian paddy fields. Subsequently detailed experiments have been conducted at Indian Agricultural Research Institute, New Delhi; Central Rice Research Institute, Cuttack and at other institutes for measurement of methane emission, and to study the role of water management, cultivars and soil properties on the emission. As a result, methane emission coefficients have been derived for different crop-management practices, which allows better quantification of the fluxes of methane and to assess the mitigation potential of different management options as a guide to policymakers.

Nitrous oxide, with its current concentration of 311 ppbV in the atmosphere, besides being an important greenhouse gas is responsible for the destruction of stratospheric ozone$^4$. Atmospheric concentration of N$_2$O is increasing at a rate of 0.22 ± 0.02% per year$^5$. The concern of N$_2$O emission is greater because of its long atmospheric lifetime of 166 ± 16 years$^6$ and higher global warming potential (310 times that of CO$_2$). From the agricultural perspective,
N₂O emission from soil represents a loss of N from the soil system and decreasing N use efficiency. Soil is considered to be one of the major sources, contributing 65% to the global nitrous oxide emission. Annual emission of N₂O–N from agricultural system amounts to 6.3 Tg, which includes the direct emission from agricultural soil and animal system and the indirect emission from agricultural soil through loss of nitrogen to aquatic system and atmosphere. The soil receiving chemical fertilizer and biologically fixed nitrogen contributes to nitrous oxide emission during the processes of nitrification and denitrification. With the advent of modern agriculture, consumption of nitrogenous fertilizer has risen sharply all over the world. This is expected to increase further to meet the food demand of the growing population. Consequently, the emission of nitrous oxide from the soil would also increase.

There are uncertainties in the estimation of methane and nitrous oxide emissions from Indian agriculture because of its diverse soil, climate, land-use types and socio-economic conditions. Moreover, various crop-management practices, water management for example, play a major role in the emission. What is the real contribution of Indian agriculture to greenhouse gas emissions and subsequent climate change, can only be answered by preparing a national inventory. This will not only improve estimates of emissions and related impact assessments, but also provide a baseline from which we may develop our future emission trajectories to identify and evaluate mitigation strategies.

In an earlier attempt, methane budget of India was estimated exploiting the relationship between biomass production and methane emission. It was observed that the effects of diurnal variation and growth duration on methane emission are ultimately reflected in the biomass production. Thus the total flux of methane could be calculated using the following equation.

\[
\text{Total methane flux (mg m}^{-2} \text{d}^{-1}) = \text{Methane emission area (m}^2) \times \text{duration of emission (30 days peak emission)} \times \text{methane emission (mg kg}^{-1}) \times \text{biomass (kg)}.
\]

Accordingly, methane emission from Indian rice fields was estimated to be 1.22 Tg per annum.

For nitrous oxide, a methodology based on the amount of each type of fertilizer N consumed (Fᵢ) and an emission coefficient \(E_i\) for the fraction of applied N that is released as nitrous oxide for each fertilizer type \(i\) was developed for preparing national inventories.\(^{10}\)

\[
\text{N}_2\text{O emission} = \Sigma \left( F_i \times E_i \right).
\]

Later, OECD/OECD revised the methodology and included the crop type to which the fertilizer is applied along with the amount of fertilizer.

\[
\text{N}_2\text{O emission} = \Sigma \left( F_{ic} \times E_{ic} \right),
\]

where \(f\) is the fertilizer type and \(c\) is the crop type.

Mosier et al.\(^7\) estimated nitrous oxide emission using the equation

\[
\text{N}_2\text{O emission} = \Sigma F \times 0.0125,
\]

where \(F\) is amount of fertilizer consumed and 0.125 is the emission coefficient.

However, both the methods for methane and nitrous oxide are too simplistic to develop an accurate inventory, for which more elaborate and accurate activity data and better validated and calibrated emission coefficients are required. The objective of this article is to estimate the budget for nitrous oxide and methane emission from Indian agricultural soils.

**Methodology for emission inventory**

**Methane**

Recently, the Inter-Governmental Panel on Climate Change (IPCC) has outlined a methodology for methane inventory preparation.\(^{11}\) Accordingly, the main rice ecosystems are irrigated, rainfed and deepwater. Within each ecosystem are water management systems, which affect the amount of methane emitted during the cropping season.

Emission (Tg yr\(^{-1}\)) = \(\Sigma \Sigma \Sigma A_{ijk} \times SF_{ijk} \times 10^{-12}\),

where \(i, j\) and \(k\) are categories under which methane emissions from paddy fields vary such as rice ecosystem, water management, cultivar, organic amendment applied, etc. \(A_{ijk}\) is the annual harvested area (m\(^2\)) under categories \(i, j\) and \(k\). For preparing the present inventory, data on area under rice cultivation for the year 1994–95 were obtained from the Fertilizer Association of India (FAI).\(^{12}\) \(EF_{ijk}\) is seasonally integrated emission factor for \(i, j\) and \(k\) conditions (g m\(^{-2}\)).

The seasonally integrated emission factors are adjusted according to the category of rice ecosystems as given below.

\[EF_i = EF_c \times SF_w \times SF_o \times SF_s,\]

where \(EF_i\) is adjusted seasonally integrated emission factor for a particular harvested area, \(EF_c\) is seasonally integrated emission factor for continuously flooded fields without organic amendments, \(SF_w\) is scaling factor to account for differences in ecosystem and water-management regime, \(SF_o\) is scaling factor for different amendment types and \(SF_s\) is scaling factor for soil type. The seasonally integrated emission factor for continuously flooded fields for different states was obtained from various studies carried at experimental stations.\(^{13–21}\) Where Indian values were not available, IPCC\(^{11}\) scaling factors for water-management regimes have been used for calcu-
lating the methane emission coefficients. Methane emission from the soil is dependent on the soil moisture content. The more the degree of anaerobicity the more is the emission of methane. The coefficients used in the present inventory are listed in Table 1.

**Nitrous oxide**

The emission of N\textsubscript{2}O that results from anthropogenic N input occurs through the direct pathways of nitrification and denitrification from soil and also through a number of indirect pathways, including volatilization losses, leaching and run-off from applied N. The applied N includes synthetic fertilizer, animal manure and sewage sludge applied to soils. Thus, the emission of N\textsubscript{2}O from the soil is dependent on the soil moisture content. The more the degree of anaerobicity the more is the volatilization\textsuperscript{22–24} to be about 15%. As majority of Indian soils are high in pH and the average annual temperature is also high compared to temperate countries, volatilization losses of N are more. Therefore, in the present calculation we have used this fraction as 15% of the applied N instead of the IPCC default value\textsuperscript{11} of 10%.

\( F_{AM} \) denotes the annual amount of animal manure nitrogen applied to soils adjusted to account for volatilization as NH\textsubscript{3} and NO\textsubscript{x}.

\[ F_{AM} = \sum T (N_T \ast \text{N}_{\text{NIT}}) \ast (1 - \text{Frac}_{\text{GASM}}) \]

\[ = [1 - (\text{Frac}_{\text{FUEL}} + \text{Frac}_{\text{PRP}} + \text{Frac}_{\text{COLLECT}} + \text{Frac}_{\text{FEED}} + \text{Frac}_{\text{CONST}})] \]

where \( T \) stands for each defined livestock category/species. In this calculation three categories of livestock, bovine, sheep and goat have been taken. \( N_T \) is the number of animals in each category\textsuperscript{25}. \( \text{N}_{\text{NIT}} \) is the annual average nitrogen excretion rate per head for each livestock category.

Data on dung produced per animal per year in different categories of livestock were reported by Gaur\textsuperscript{26}. Dry matter content in the fresh dung is 18% in the case of bovine and 32% in the case of sheep and goat\textsuperscript{27}. N content (oven-dry weight basis) is 1.0% in bovine dung and 1.87% in sheep and goat dung\textsuperscript{28}. From these datasets, average N excretion annually for each livestock category has been calculated.

\( \text{Frac}_{\text{GASM}} \) is the fraction of N that volatilizes as NH\textsubscript{3} and NO\textsubscript{x}, which is taken to be 15% of the N content of manure\textsuperscript{29,25}. \( \text{Frac}_{\text{FUEL}} \) denotes animal manure that is burnt for fuel, \( \text{Frac}_{\text{PRP}} \) is the fraction of animal manure deposited on soil by grazing livestock, \( \text{Frac}_{\text{COLLECT}} \) is the fraction of animal manure used as construction\textsuperscript{26}. \( \text{Frac}_{\text{FEED}} \) is the fraction of animal manure used as feed. This fraction has been assumed to be zero in the present estimation, as animal manure is hardly used as animal feed in India. \( \text{Frac}_{\text{CONST}} \) is the loss during collection of dung. It has been taken as 30% of the dung produced\textsuperscript{29}.

**Table 1.** Coefficients used in the present inventory

<table>
<thead>
<tr>
<th>Parameter</th>
<th>IPCC coefficients</th>
<th>Revised coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>EF\textsubscript{c}, seasonally integrated emission factor for continuously flooded fields</td>
<td>200 kg ha\textsuperscript{-1}</td>
<td>State-specific coefficients</td>
</tr>
<tr>
<td>SF\textsubscript{w} (scaling factor for different water ecosystems)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous flooding</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Rainfed</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Upland</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Deepwater</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>EF\textsubscript{1} (N\textsubscript{2}O emission from applied fertilizer; %)</td>
<td>1.25</td>
<td>0.7</td>
</tr>
<tr>
<td>EF\textsubscript{2} (N\textsubscript{2}O emission from organic soil; %)</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>EF\textsubscript{3} (N\textsubscript{2}O emission from volatilized N from fertilizer and manure; %)</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>EF\textsubscript{4} (N\textsubscript{2}O emission from leached and run-off N from fertilizer and manure; %)</td>
<td>2.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Frac\textsubscript{GASM} (gas loss through volatilization from inorganic fertilizer; %)</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>Frac\textsubscript{GASM-AM} (gas loss through volatilization from manure; %)</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>Frac\textsubscript{COLLECT} (leaching loss of N from applied fertilizer and manure; %)</td>
<td>30</td>
<td>10</td>
</tr>
</tbody>
</table>

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\[ F_{BN} = \text{CropBF} \times \text{FracCRBN} \]

where \text{CropBF} is seed yield of N-fixing crops.\(^2\) Four crops, i.e. gram, arhar, groundnut and soybean were taken into account for the calculation. \text{FracCRBN} is the N content of grain and straw of legumes.\(^3\)

\[ F_{CR} = \text{CropST} \times \text{FracCRST} + \text{CropSBF} \times \text{FracCRSBF} \]

where \text{CropST} is the amount of straw of non-N-fixing crops incorporated to the soil as residue and \text{CropSBF} is the amount of straw of N-fixing crops incorporated to the soil as residue that can be calculated by the following formula.

\[
\text{Straw yield} = (\text{Grain yield}/\text{harvest index}) - \text{grain yield.}
\]

Grain yield data were obtained from FAI\(^{12}\) and harvest index values from Bandyopadhyay \textit{et al.}\(^{30}\). It is assumed that only 5% of straw produced is incorporated to the soil for all crops. In India, crop residues are used for fuel, feed and other domestic purposes. In Punjab, Haryana and western Uttar Pradesh, for example, rice straw is burnt. Therefore, very little of crop residues are incorporated in the field.

\text{FracCRST} is the nitrogen content of residue of non-N fixing crops and \text{FracCRSBF} is the N content of residue of N-fixing crops.\(^9\) Eleven major crops grown in India were chosen for the calculation.

\[ F_{OS} = \text{area of organic soil harvested (area of organic soil cultivated annually).} \]

Organic soils are those containing more than 12% to 18% of organic carbon depending upon the clay content.\(^11\) Indian soils are generally deficient of organic carbon (contain less than 1%). Only some soils in Kerala and northeast hill regions contain higher organic carbon (about 5%). Therefore, in the present estimation the area under organic soil has been taken as nil.

\[ \text{EF1} = \text{the emission factor (0.7%) for N}_2\text{O–N emitted from the various nitrogen additions to the soil.} \]

This value is based on studies conducted in India\(^ {33–35}\), which showed that emission of N\(_2\)O–N from fertilized soil under rice and wheat is about 0.79 kg ha\(^{-1}\), when 120 kg N ha\(^{-1}\) was applied. Different coefficients used by IPCC\(^ {11}\) and the present inventories are listed in Table 1.

### Indirect N\(_2\)O emission

The following equation was used for the calculation of indirect emission of N\(_2\)O (N\(_2\)O\(_{\text{indirect}}\)).

\[ \text{N}_2\text{O}_{\text{indirect}} = \text{N}_2\text{O}(G) + \text{N}_2\text{O}(L) \]

where \text{N}_2\text{O}(G) is the N\(_2\)O produced from volatilization of applied fertilizer and animal manure N and its subsequent atmospheric deposition as NO\(_x\) and NH\(_x\). This is further calculated as

\[ \text{N}_2\text{O}(G) = [(\text{N} \times \text{FUEL}) + \text{N} \times \text{PRP-AM} + \text{N} \times \text{COLLEC}] \times \text{EF4}, \]

where \text{N} \times \text{FUEL} is the amount of fertilizer consumed annually, \text{FUEL} \times \text{PRP-AM} \times \text{N} \times \text{COLLEC} is the fraction of fertilizer that volatilizes as NH\(_3\) and NO\(_x\) \times \sum_{\text{N} \times \text{AM}} \times \text{FracAM} \text{EF4} \times \text{EF5}, \]

where \text{N} \times \text{AM} is N\(_2\)O produced from leaching and run-off of applied fertilizer and animal manure N, \text{FracAM} \times \text{EF5} denotes animal manure that is burnt for fuel\(^ {36}\), \text{FracAM} \times \text{EF5} is the fraction of animal manure that is deposited on the soil by grazing livestock. In India, this practice is assumed to contribute negligible amounts of manure to the soil and hence has been taken as nil. \text{FracAM} \times \text{EF5} is the loss of dung during collection. \text{FracAM} \times \text{EF5} is the fraction of animal manure that is used as construction\(^ {36}\), \text{FracAM} \times \text{EF5} is the fraction of animal manure that is being fed (in the Indian perspective, it is less and assumed to be zero). \text{FracAM} \times \text{EF5} is the fraction of N lost through leaching, which is 10% of the applied N\(^ {36}\). \text{FracAM} \times \text{EF5} is the emission factor for deposited N from leaching and run-off (kg N\(_2\)O–N kg\(^{-1}\) N leached and run-off), which is taken as 0.5.

\[ \text{Total N}_2\text{O–N emission: N}_2\text{O–N}_{\text{TOTAL}} = \text{N}_2\text{O–N}_{\text{TOTAL}} = \text{N}_2\text{O–N}_{\text{TOTAL}} + \text{N}_2\text{O–N}_{\text{TOTAL}} \]

### Current emission estimates

\[ \text{Methane} \]

The emission of methane from Indian rice fields for the year 1994–95 was estimated to be 2903 Gg (Gg = 10\(^{12}\) g
or thousand tonne; Table 2). Andhra Pradesh emitted the highest amount of CH$_4$ (529 Gg) followed by West Bengal (448 Gg) and Tamil Nadu (404 Gg). Larger area under rice cultivation in irrigated, continuously submerged water regime (3.45 m ha) in Andhra Pradesh was responsible for higher emission. Though the rice-growing area in irrigated ecosystem in Uttar Pradesh was also high (3.47 m ha), rice fields in most regions are intermittently dried resulting in lower emission of methane (120 Gg). In rainfed ecosystem, the major area under rice cultivation was in Madhya Pradesh and this area is generally drought-prone, resulting in low emissions of methane. The maximum area under deepwater rice was in West Bengal followed by Bihar. In West Bengal, out of total methane emission of 447 Gg, the deepwater rice ecosystem contributed to 109 Gg of methane. Though the rice-growing area in irrigated ecosystem in Uttar Pradesh was also high (3.47 m ha), rice fields in most regions are intermittently dried resulting in lower emission of methane (120 Gg). In rainfed ecosystem, the major area under rice cultivation was in Madhya Pradesh and this area is generally drought-prone, resulting in low emissions of methane. The maximum area under deepwater rice was in West Bengal followed by Bihar. In West Bengal, out of total methane emission of 447 Gg, the deepwater rice ecosystem contributed to 109 Gg of methane.

The total area under rice cultivation during the year 1994–95 was 42.24 mha. Among the various rice ecosystems, the largest cultivated area of 14.41 mha was under lowland, rainfed rice and contributed to 0.746 Tg (26%) of methane emission (Figure 1). Maximum emission of 1.379 Tg (47%) was obtained from irrigated, continuously flooded moisture regime (10.97 mha). The area under irrigated, intermittently flooded rice (10.45 mha) was comparable to rice area under continuous flooded rice, but the emission under this moisture regime was reduced to one-third (17%). Ten per cent emissions of methane were obtained from deepwater rice, as a small area of 2.22 mha was cultivated in this ecosystem. Upland rice grown over 4.2 mha of land did not contribute to methane emission. According to our estimates using IPCC default emission coefficients, Indian paddy soil emitted 4.7 Tg of methane annually (Table 3).

### Nitrous oxide

Emission of N$_2$O–N was estimated to be 79.94 Gg for the year 1994–95 (Table 2). Uttar Pradesh (including Uttaranchal) emitted the highest amount of N$_2$O–N (15.53 Gg) followed by Andhra Pradesh (9.50 Gg) and Maharashtra (7.50 Gg). Larger area under cultivation, higher use of N fertilizer and greater animal population are responsible for higher emission in these states. Estimates of N$_2$O–N emission in India from 1980–81 onwards ranged from 32.84 Gg (1980–81) to 93.82 Gg (2000–01) per year (Figure 2). There was a linear increase in emission due to increased area under different crops, higher use of N fertilizers and also increase in animal population. It was observed that inorganic fertilizer is the major contributor (72%) of nitrous oxide (Figure 3). Other sources like crop residues and manure contribute 11 and 3% respectively to the total emission.

### Global warming potential of Indian agricultural soil

Global warming potential (GWP) is an index defined as the cumulative radiative forcing between the present and...
some chosen later time ‘horizon’ caused by a unit mass of gas emitted now. It is used to compare the effectiveness of each greenhouse gas to trap heat in the atmosphere relative to some standard gas, by convention CO$_2$. The GWP for CH$_4$ (based on a 100-year time horizon) is 21, while that for N$_2$O is 310, when GWP value for CO$_2$ is taken as 1. GWP of methane and nitrous oxide emitted was calculated using the following equation$^1$.

$$\text{GWP} = \text{Methane emission} \times 21 + \text{Nitrous oxide emission} \times 310.$$ 

Table 3. Emission of CH$_4$ and N$_2$O-N in different states of India during 1994–95 using IPCC coefficients

<table>
<thead>
<tr>
<th>State/Union territory</th>
<th>Methane (Gg)</th>
<th>Nitrous oxide (Gg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andaman and Nicobar Islands</td>
<td>1.2</td>
<td>0.033</td>
</tr>
<tr>
<td>Andhra Pradesh</td>
<td>701.2</td>
<td>17.282</td>
</tr>
<tr>
<td>Arunachal Pradesh</td>
<td>17.6</td>
<td>0.009</td>
</tr>
<tr>
<td>Assam</td>
<td>314</td>
<td>0.372</td>
</tr>
<tr>
<td>Bihar</td>
<td>375.2</td>
<td>7.114</td>
</tr>
<tr>
<td>Dadra and Nagar Haveli</td>
<td>1.2</td>
<td>0.011</td>
</tr>
<tr>
<td>Delhi</td>
<td>0.4</td>
<td>0.178</td>
</tr>
<tr>
<td>Goa, Daman and Diu</td>
<td>11.2</td>
<td>0.049</td>
</tr>
<tr>
<td>Gujarat</td>
<td>106.4</td>
<td>8.185</td>
</tr>
<tr>
<td>Haryana</td>
<td>158</td>
<td>7.978</td>
</tr>
<tr>
<td>Himachal Pradesh</td>
<td>2</td>
<td>0.471</td>
</tr>
<tr>
<td>Jammu and Kashmir</td>
<td>50</td>
<td>0.576</td>
</tr>
<tr>
<td>Karnataka</td>
<td>39.6</td>
<td>7.904</td>
</tr>
<tr>
<td>Kerala</td>
<td>20.4</td>
<td>1.296</td>
</tr>
<tr>
<td>Madhya Pradesh</td>
<td>80.4</td>
<td>12.264</td>
</tr>
<tr>
<td>Maharashtra</td>
<td>26.8</td>
<td>13.641</td>
</tr>
<tr>
<td>Manipur</td>
<td>17.2</td>
<td>0.104</td>
</tr>
<tr>
<td>Meghalaya</td>
<td>9.2</td>
<td>0.030</td>
</tr>
<tr>
<td>Mizoram</td>
<td>428.68</td>
<td>0.006</td>
</tr>
<tr>
<td>Nagaland</td>
<td>20.4</td>
<td>0.961</td>
</tr>
<tr>
<td>Orissa</td>
<td>586</td>
<td>2.439</td>
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<tr>
<td>Pondicherry</td>
<td>6</td>
<td>0.168</td>
</tr>
<tr>
<td>Punjab</td>
<td>226.4</td>
<td>14.037</td>
</tr>
<tr>
<td>Rajasthan</td>
<td>6.4</td>
<td>7.820</td>
</tr>
<tr>
<td>Sikkim</td>
<td>4</td>
<td>0.012</td>
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<tr>
<td>Tamil Nadu</td>
<td>444.4</td>
<td>7.911</td>
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<tr>
<td>Tripura</td>
<td>35.2</td>
<td>0.076</td>
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<tr>
<td>Uttar Pradesh</td>
<td>268.8</td>
<td>28.313</td>
</tr>
<tr>
<td>West Bengal</td>
<td>736.4</td>
<td>6.160</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4695</strong></td>
<td><strong>144.94</strong></td>
</tr>
</tbody>
</table>

The contribution of Indian agriculture (current estimates) towards greenhouse gas emissions and its GWP compared to the world agriculture during 1990 is presented in Table 4. According to our estimates, methane and nitrous oxide from Indian agricultural soils are responsible for only about 0.23% and 0.1% respectively, of the global warming caused by world’s CO$_2$ emissions (Table 4). The total global warming potential of Indian agricultural soil is 85,729 Gg equivalents of CO$_2$ (Table 2).

Indian agriculture as a whole contributed only 3% of the world total methane emissions (375 Tg), of which 25% is from agricultural soils (Table 4). In the agriculture sector livestock is a larger source than rice fields, contributing three times more methane. Among the states, the GWP of Andhra Pradesh was the highest followed by West Bengal and Tamil Nadu (Table 2). Even though the highest nitrous oxide emission was from Uttar Pradesh, it had a lower GWP because of lower methane emission from predominantly intermittently irrigated rice.

In terms of nitrous oxide emission, the contribution of Indian agriculture as a fraction of the world agriculture is miniscule. In an earlier estimate$^{38}$, emission of 243 Gg of N$_2$O was ascribed to Indian agriculture (Table 4). Out of this, 240 Gg was contributed by Indian agricultural soil and 3 Gg was due to burning of agricultural residues. For the year 1994–95 using the IPCC default emission coefficients, the value of nitrous oxide emissions was found to be 145 Gg (Table 3). Our present estimates using indigenous emission coefficients have shown that the Indian agricultural soil is contributing only 79.94 Gg of nitrous oxide. Based on these estimates, the contribution of Indian agriculture will be revised to 120 Gg of N$_2$O-N annually.

Figure 2. Emission of N$_2$O-N (’000 tons) in India during 1980–2000.

Figure 3. Contribution of different sources towards total nitrous oxide emission.
Conclusion

This study has shown that the contribution of Indian agricultural soil to greenhouse gas emissions and its GWP is small compared to earlier estimates. Emission of methane as well as nitrous oxide is several times higher when default emission coefficients given by IPCC are used for calculation. IPCC gives the same coefficients for a particular rice ecosystem irrespective of soil conditions and production system management. Using the IPCC default emission coefficients, the annual methane emission from paddy cultivation was estimated to be 4.1 Tg \(\text{CO}_2\) and annual emission of nitrous oxide from Indian agricultural soil was estimated to be 145 Gg \(\text{N}_2\text{O}\). Therefore, GWP of Indian agriculture as estimated by the IPCC default values is considerably higher and needs revision. In the present article we have used emission coefficients for methane that are based on specific experiments carried out at various rice-growing regions across the country under different moisture regimes. In case of nitrous oxide, the methodology accounts for emission of nitrous oxide not only from fertilizer application, but also takes into account other sources like crop residue and animal manure incorporation in the soil. The indirect sources of nitrous oxide emission, i.e. fertilizer leached as nitrate and volatilized as ammonia are also accounted for in the present inventory. Accordingly, methane and nitrous oxide from Indian agricultural soils are responsible for only about 0.23 and 0.1% respectively, of the global warming caused by the world’s \(\text{CO}_2\) emissions. Thus overall greenhouse gas emission from Indian agriculture, especially from the soil is a small fraction of the total world greenhouse gas emission.

Table 4. Methane and nitrous oxide emissions from agriculture and their global warming potential

<table>
<thead>
<tr>
<th></th>
<th>(\text{CO}_2) (Tg)</th>
<th>(\text{CO}_2) (% of the world)</th>
<th>(\text{CH}_4) (Tg)</th>
<th>(\text{CH}_4) (% of the world)</th>
<th>(%\text{GW of} \ \text{CH}_4) caused by (\text{CO}_2)</th>
<th>(%\text{GW of} \ \text{N}_2\text{O}) caused by (\text{CO}_2)</th>
<th>(%\text{GW of} \ \text{N}_2\text{O}) (% of GWP of (\text{N}_2\text{O}) the world)</th>
</tr>
</thead>
<tbody>
<tr>
<td>World(^ {13})</td>
<td>26400</td>
<td>100</td>
<td>375</td>
<td>100</td>
<td>7875</td>
<td>29.8</td>
<td>8.96</td>
</tr>
<tr>
<td>India(^ {13})</td>
<td>585</td>
<td>2.1</td>
<td>17.7</td>
<td>4.7</td>
<td>371.7</td>
<td>1.4</td>
<td>0.26</td>
</tr>
<tr>
<td>World agriculture(^ 1)</td>
<td>-</td>
<td>-</td>
<td>167.5</td>
<td>44.7</td>
<td>3517.5</td>
<td>13.3</td>
<td>3.5</td>
</tr>
<tr>
<td>Indian agriculture(^ 1)</td>
<td>-</td>
<td>-</td>
<td>11.8</td>
<td>3.2</td>
<td>223.4</td>
<td>0.85</td>
<td>0.24</td>
</tr>
<tr>
<td>Agricultural soil(^ 1)</td>
<td>-</td>
<td>-</td>
<td>2.9</td>
<td>0.77</td>
<td>60.9</td>
<td>0.23</td>
<td>0.08</td>
</tr>
</tbody>
</table>

2. \(\text{CO}_2\) equivalents are based on GWP of 1 for \(\text{CO}_2\), 21 for \(\text{CH}_4\) and 310 for \(\text{N}_2\text{O}\).

20. Barauh, K. K., Project report of Department of Science and Technology funded project on methane emission from rice fields in different agro-climatic zones of Assam, 2002.


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