Global estimations of the inventory and mitigation potential of methane emissions from rice cultivation conducted using the 2006 IPCC guidelines

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Abstract

While there have been many estimates of global CH_4 emissions from rice fields, none of them have been obtained using the IPCC guidelines. In this study, we used the Tier 1 method described in the 2006 IPCC guidelines to estimate the global CH_4 emissions from rice fields. To accomplish this, we used country-specific statistical data regarding rice harvest areas and expert estimates of relevant agricultural activities. The estimated global emission for 2000 was 25.4 Tg/yr, which is at the lower end of earlier estimates and close to the total emission summarized by individual national communications. Monte Carlo simulation revealed a 95% uncertainty range of 14.8 to 41.5 Tg/yr. We estimated that, if all of the continuously flooded rice fields were drained at least once during the growing season, the CH_4 emissions would be reduced by 4.1 Tg/yr. Furthermore, we estimated that applying rice straw off-season wherever and whenever possible would result in a further reduction in emissions of 4.1 Tg/yr globally. Finally, if both of these mitigation options were adopted, the global CH_4 emission from rice paddies could be reduced by 7.6 Tg/yr.

Key Words

Methane, rice field, IPCC guidelines, emission inventory, mitigation potential

Introduction

Although the total source strength of global atmospheric CH_4 is relatively certain, the strength of individual sources remains uncertain (Lelieveld *et al.* 1998). Using the global source strength and assuming that 80 Tg CH_4 /yr are emitted from rice fields, Houweling *et al.* (2000) modeled the global distribution of atmospheric CH_4. Frankenberg *et al.* (2005) subsequently compared these modeled results to satellite observations and found discrepancies over India and the tropics, indicating that the rice emissions used in the model were probably overestimated. Keppler *et al.* (2006) recently reported that CH_4 is emitted from terrestrial plants under oxic conditions, which resulted in the addition of 62-236 Tg CH_4 /yr to the CH_4 budget. Although later recalculations and modeling studies reduced the plant contribution to 52.7-85 Tg CH_4 /yr (Parson *et al.* 2006; Houweling *et al.* 2006), these findings still indicate that it is necessary to re-evaluate the CH_4 emissions from other sources. The United Nations Framework Convention on Climate Change requires all signatories to develop and periodically update national inventories of anthropogenic emissions by source. Most signatories have submitted their national communications using 1994 as the base year, and annex I countries have submitted their national inventory reports on annual basis. Although most countries used the 1996 guidelines to estimate the CH_4 emission from rice cultivation, some major rice-producing countries developed their own emission factors based on local measurements or used models. The purpose of this study is to provide an updated estimate of CH_4 emission from global rice fields using the tier 1 method described in the 2006 IPCC guidelines with the default emission factors and country- or region-specific agricultural activity data for individual rice producing countries.

Methods

2006 IPCC Guidelines

We used the Tier 1 method in the IPCC guidelines (IPCC, 2007), in which the emission from a country is the sum of emissions from fields under each specific condition, as shown in Equation 1.

$$CH_{4Rice} = \sum_{i,j,k} EF_{i,j,k} \times T_{i,j,k} \times A_{i,j,k} \times 10^{-6} \tag{1}$$

where CH4Rice is the annual CH_4 emission from rice cultivation in a country or region in Gg CH_4 /yr, $EF_{i,j,k}$ is a daily emission factor specific for *i, j,* and *k* conditions in kg CH_4 /ha day-1, $T_{i,j,k}$ is the cultivation period of rice for *i, j,* and *k* conditions in days, $A_{i,j,k}$ is the annual harvested area of rice for i, j, and k conditions in ha /yr, and i, j, and k represent different ecosystems, water regimes, types and amounts of organic amendments, and other conditions under which CH_4 emissions from rice may vary.

As shown in Equation 2, the daily specific emission factor is estimated from a baseline EF and various SFs to account for the water status during and before the rice season, as well as the types and amounts of organic fertilizers used.

$$EF_i = EF_c \times SF_w \times SF_p \times SF_o \times SF_{s,r} \qquad (2)$$

where *EFi* is the adjusted daily emission factor for a particular harvested area, *EFc* is the baseline emission factor for continuously flooded fields without organic amendments, *SFw* is the scaling factor for differences in the water regime during the cultivation period, *SFp* is the scaling factor for differences in the water regime in the pre-season prior to the cultivation period, *SFo* is the scaling factor for both the type and amount of organic amendment applied, and *SFs,r* is the scaling factor for soil type, rice cultivar, etc., if available.

Source of activity data

Data for the lowland rice area for the year 2000 were collected at the sub-national level for monsoon Asian countries and the United States using country-specific statistics. Data for other countries were collected from the Food and Agriculture Organization's statistical database (http://faostat.fao.org/). The areas of rice fields that were irrigated and rainfed were scaled according to Huke and Huke (1997). Other information on water status and the use of organic fertilizer were obtained from various literatures and expert estimation.

Sensitivity analysis

The sensitivity of the estimated emission to variation in the input parameters was evaluated using the Risk Analysis Add-in for Microsoft Excel version 4.5 (Palisade Corporation). Input parameters included a baseline emission factor, various scaling factors, the amount of organic amendment, and the proportions of rice fields under different water regimes during the rice-growing season and preseason. The baseline emission factor and all of the scaling factors have a lognormal distribution (Yan *et al.* 2005) with a mean and range that is provided in the 2006 IPCC guidelines. The amount of organic amendment is country-specific as estimated above; however, we assumed it was normally distributed with a coefficient variation (CV) of 30%. We have estimated the ratios of the water regimes of irrigated rice fields under continuous flooding, single drainage, and multiple drainage for each country on an individual basis, as described above. In addition, we assumed that the proportion of fields under continuous flooding had a CV of 30%, and that when this value varied it had a trade-off relationship with the ratio of irrigated rice fields under single and multiple drainage. The ratio of rice fields with different preseason water statuses defined in the previous section were all assumed to have an exponential distribution.

Results

We estimated a global emission of 25.4 Tg CH_4 /yr, of which 18.9 Tg was from irrigated rice fields and 6.4 Tg was from rainfed and deepwater rice fields. As shown in Table 3, which presents the emission by individual countries, more than half of the global emission from rice fields occurred in China and India, while more than 90% of the global emission from rice fields was from monsoon Asian countries. Our estimate is at the lower end of the early estimates. A major reason for the discrepancy between our estimate and previously published global totals may be that we distinguished rice ecologies and water management practices (i.e., continuously flooded, intermittently irrigated, rainfed, or deepwater rice fields).

Table 1. Estimated emissions from global rice fields, Tg CH_4 /yr.

Region/country	Irrigated rice	Rainfed and deepwater rice	Total
China	7.41	0.00	7.41
India	3.99	2.09	6.08
Bangladesh	0.47	1.19	1.66
Indonesia	1.28	0.38	1.65
Vietnam	1.26	0.39	1.65
Myanmar	0.80	0.36	1.17
Thailand	0.18	0.91	1.09
Other monsoon Asian countries	2.32	0.67	2.99
Rest of the world	1.20	0.49	1.70
Total	18.90	6.49	25.39

The areas with the greatest emissions were the delta regions of large rivers in Bangladesh, Myanmar, and Vietnam. In addition, the generated map revealed that other areas with high emissions were found on the island of Java in Indonesia, central Thailand, southern China and the southwestern portion of the Korean peninsula (Figure 1).

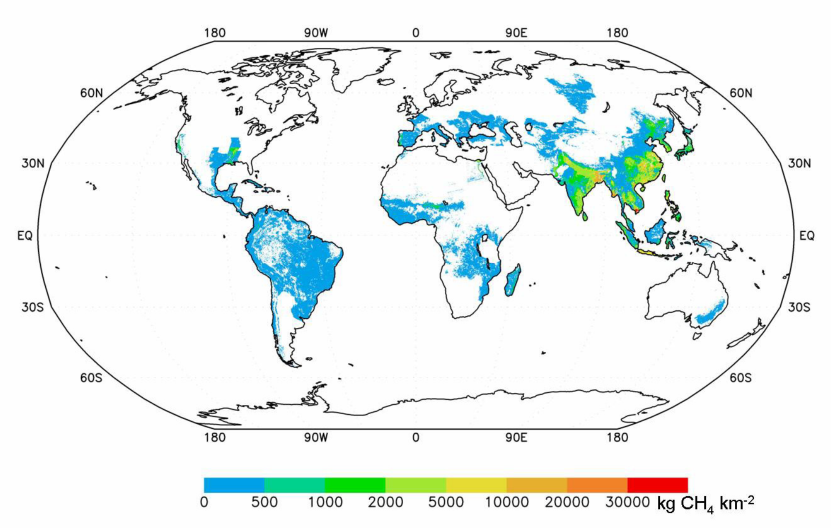

Figure 1. Estimated annual methane emission from global rice paddies at a spatial resolution of 5 minutes.

We ran 10,000 Monte Carlo simulations using the error ranges of the baseline emission factor and scaling factors provided in the 2006 IPCC guidelines and the assumed error ranges of the activity data to test the sensitivity of the estimated emissions to the controlling factors. The 95% variation range for the estimated emissions was 14.8 to 41.5 Tg/yr and the estimated emissions were most sensitive to variation in the baseline EF (Figure 2). This is primarily due to the large variability in the baseline EF, which includes the contribution of many influencing factors that are not considered in the guidelines. The estimated emissions were also highly sensitive to the amount of organic amendment and the fraction of rice fields under continuous flooding (Figure 2), indicating that reliable information regarding agricultural activities is crucial to improving the accuracy of emission inventories.

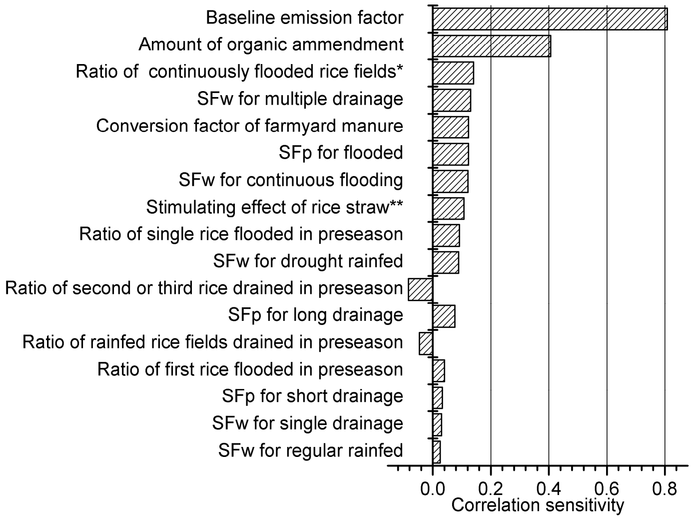

Figure 2. Correlation sensitivity of the estimated methane emission to input parameters calculated using the Risk Analysis Add-in for Microsoft Excel version 4.5 (Palisade Corporation). * Fraction of irrigated rice fields continuously flooded during the rice growing season.

Because continuous flooding increases the amount of CH_4 emitted from rice fields, another mitigation option is to drain continuously flooded fields once or more during the rice-growing season. Indeed, adoption of this practice would result in a reduction of 4.1 Tg/yr. It is well known that the water regime exerts a trade-off effect on CH_4 and nitrous oxide (N_2O) emissions from rice fields. Even though the global warming potential of 1 kg of N_2O is approximately 12 times higher that of 1 kg of CH_4, the increased global warming potential resulting from this amount of N_2O emission is only approximately 2.7% of the reduced global warming potential that would result from the 4.1 Tg reduction in CH_4 emission. Therefore, it is favourable to reduce CH_4 emissions from rice fields by draining the fields.

Conclusion

Using the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and country-specific activity data, we estimated that the emission of CH_4 from global rice fields is 25.4 Tg/yr, with a 95% certainty range of 14.1-41.5 Tg/yr. Although the estimated emissions for individual countries do not always agree well with the national communications, the estimated global emissions are very close to the sum of the individual national communications. These results indicate that the emission of CH_4 from rice paddies was overstated in most earlier atmospheric models, which allows for a new CH_4 source or higher estimated CH_4 emissions for other sources. Draining the continuously flooded rice paddies once or more during the rice-growing season would also reduce global emissions by 4.1 Tg CH_4 /yr. Furthermore, the increased global warming potential resulting from increased N2O emission due to draining the fields would be negligible when compared to the reduction in global warming potential that would occur as a result of the reduced CH_4 emissions.

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