RICE-ECOSYSTEMS OF INDIA IN THE CONTEXT OF METHANE EMISSION

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ABSTRACT:

The rice land is linked to the climate change due to its methane emission potential. The systems of growing rice and associated soil and crop management practices that have evolved are varied and complex. However, from the methane emission point of view, water regime is a crucial parameter. According to IPCC guidelines the rice ecosystem need to be categorized into four strata for methane emission study. Ancillary data on rainfall, elevation, soil, command area/ irrigation statistics were used with remote sensing derived rice maps in GIS to categorise the rice lands into four strata as: irrigated, rain fed flood prone and rain fed drought prone and others. *In-situ* weekly measurements of methane emission from the representative ecosystems was collected and analysed using gas chromatography following the IPCC standards for three consecutive years; 2003, 2004 and 2005. This paper highlights the results of the study carried out to stratify the rice lands of India into different strata and methane emission pattern observed using *in-situ* measurements. Results showed that the major stratum emerged as the rainfed drought prone with 42.8 per cent of total rice lands (wet season) and found in many states. Rainfed flood prone accounted for around 9.6 per cent, mainly found in Assam, Bihar, WB, Orissa, AP. Irrigated stratum occupied 38.8 per cent during wet season. The irrigated intermittent category was prevalent in the northwestern regions in about 8.8 per cent of the area. The CH_4 emission pattern of irrigated crop in dry season showed a steady increase in the beginning which peaks during flowering stage, decreasing gradually there after. The results were consistent for different varieties and across the years. The emission pattern of irrigated wet season crop showed two peaks. The emission pattern also showed the influence of crop variety as well as year (of observation).

1. INTRODUCTION

The rice land is linked to the climate change due to its methane emission potential. Rice cultivation has been accredited as one of the most important source of anthropogenic methane, a greenhouse gas with estimates of annual emission ranging between 29 and 61 Tg/yr, representing 8.5-10.9 percent of total emission from all sources. (Crutzen, 1995 and Houghton *et al*, 1995, IPCC, 2002). Rice ecology plays a significant role in methane emission. The systems of growing rice and associated soil and crop management practices that have evolved are varied and complex. The term rice ecology is introduced from the environmental conditions in which rice is grown. At the global level, rice ecologies have been classified into two broad categories: Irrigated and fragile. Out of 155 m ha of the rice grown in the world, around 58% (93 m ha) is irrigated, however, these contribute to 75% of the total rice production. In India, irrigated rice constitutes only 48% of the area while other ecologies account for the rest (rainfed lowland -29%, uplands-14%, deepwater-7%, and coastal wetlands-2%). The rice ecology and methane emission has direct relationship through to flooding periods, intensity and duration. However, no systematic data on rice ecology exists especially in spatial form. The differences in crop calendars, season lengths, cultural practices, diverse cultivars, manure addition, organic matter decomposition, weather and many other factors impede direct comparisons of methane emissions from different rice ecologies.

The anaerobic condition and duration has a direct relationship with methane emission. With the intensification of rice cultivation to meet the increased global demand, CH_4 emission from this important ecosystem is anticipated to increase. India and China are thought to be the major contributors to global CH_4 budget because of their large areas under paddy cultivation. It has been estimated that global rice production must almost double by the year 2020 in order to meet the growing demand (Hossain, 1997) and this may increase CH_4 fluxes (Bouwman, 1991) by up to 50%. With the understanding that rice paddies are a major source of atmospheric CH_4 and N_2O, there is a need for careful evaluation of the source strength of this ecosystem, and of the influence of soil, water and crop management practices on both grain yield and GHG fluxes. A major challenge in meeting this objective lies in reducing the large uncertainties associated with regional and global level estimates of GHG emissions (IRRI, 2000).

India is a Party to the UNFCCC- a multilateral treaty (UNFCCC, 1992). UNFCCC entered into force on 21st March 1994 and as per this a national inventory of anthropogenic emissions by sources and removals by sinks of all GHGs must be generated using comparable methodologies. IPCC guidelines (IPCC, 1996) emphasize the need to improve transparency, consistency, comparability, completeness and accuracy in inventories. Methane emission from agriculture is still considered to be associated with high uncertainty as per IPCC Third Assessment Report. The UNFCCC has made it mandatory for nations to communicate their GHG inventories (CH_4, N_2O and CO_2) according to IPCC methodology. The basic requirements for national inventory is the generation seasonal of rice crop maps, rice calendar, rice (ecology) strata maps and strata-wise emission details.

There are large spatial and temporal variations of methane fluxes due to varying water regime, soil type and texture, organic amendments and application of fertilizers, varieties, soil organic carbon, cultivation practices etc (Neue and Sass, 1994, Gupta and Mitra, 1999). Soils have important influences on the production, oxidation, accumulation of, and emissions of CH_4 (Kumaraswamy *et al*, 2000). Incorporation of green manure in the form of Azolla led to reduction in methane emission (Bharati *et al*, 2000). The methane emission measurement using automatic measurement systems (closed chamber method) at Cuttack rice fields were studied to test the impact of water regime, organic amendment, inorganic amendment and rice cultivars (Adhya *et al*, 2000). The methane emission during the wet season 1996 was 42 CH_4 kg ha^{-1}. The intermittent irrigation reduced the emissions by 15 % as compared to continuous flooding with 20 to 44 CH_4 kg ha^{-1}. The emission from rainfed ecosystem was 32 kg CH_4 ha^{-1} yr^{-1}. The non-flooded conditions exhibited a single peak at vegetative stage, flooded conditions showed additional peak at reproductive stage (Bharati *et al*, 2001) thus emphasizing the necessity of a systematic investigation of CH_4 flux from a variety of rice ecologies.

Remote sensing data offers a wide spectrum of ground resolution that is ideally suited for various scales of mapping. Multi-temporal satellite data is the only feasible source of monitoring large agricultural units to create a spatial database of the various components of the existing agro-ecosystem. Studies carried out within the country and elsewhere have demonstrated that multispectral remotely sensed data could be used effectively to identify major crops and to determine their area of extent (Manjunath *et al*, 2000, Dadhwal *et al*, 2002). The remote sensing data aids in deriving spatial information of rice crop distribution (Xiao *et al*, 2006) and crop dynamics. This in conjugation with collateral data on methane emission controlling factors is useful for deriving rice strata for methane sampling in GIS environment.

The current paper is aimed at development of techniques of stratification of riceland using remote sensing and collateral data into IPCC compliance categories and collection of *in-situ* methane samples for understanding the methane emission pattern across the diverse rice ecologies of India.

2. MATERIAL AND METHODS

2.1 Study Area and Data Used

The rice crop is grown in all most all parts of the country. The average rice area in the country is around 44 Mha. The study area encompassed entire country excluding Sikkim, Tripura, Nagaland, Manipur, Arunachal Pradesh, Mizoram, Meghalaya and Islands. The states selected for methane sampling were Andhra Pradesh, Assam, Bihar, Haryana, Jammu & Kashmir, Karnataka, Madhya Pradesh, Orissa, Punjab, Tamil Nadu, West Bengal and Uttar Pradesh which account for 82 % of the total rice area.

The multidate SPOT 4 VEGETATION S10 NDVI composites (April 2001-May 2002) and IRS 1C/1D WiFS 2002 were used for deriving the seasonal rice maps of the study region. The elevation data available on USGS 2002 GTOPO30 website (http://edc.usgs.gov//products/elevation/gtopo30/) has been used as the source for DEM (1 km grid developed from 300 m contour interval which has accuracy of 18 m rmse). The IMD rainfall data of 30 years from 188 meteorological stations was used to generate monthly normal rainfall maps. The irrigation atlas of India (Survey of India-SOI) was used to generate command area map. The source of soil map was SOI (SOI, 1978) at 1:6 M scale. Administrative boundaries (states and district) of Survey of India at 1:2.5 M scale (SOI) maps were used. Archive statistics of rice crop area and district level irrigation source were taken from Department of Agriculture (Govt. of India), Directorate of Economics and Statistics of concerned states. Ground truth data for classification of satellite images for rice area mapping was taken from other on-going projects (FASAL, Cropping system analysis).

2.2 Methodology

The methodology for deriving seasonal rice maps using multidate remote sensing data and stratification has been described in detail by Manjunath and Panigrahy, 2009 (this workshop) and Manjunath et al. 2006.

2.2.1 Stratification of Rice lands: As per the IPCC (1996) guidelines, it is desirable to classify rice area into strata and sub strata such as Irrigated, rainfed, deep water and other. For the present study we have categorized the rice lands into 5 categories as irrigated (continuous flooding), irrigated (intermittent flooded–multiple aeration), rainfed low land (flood prone), rainfed lowland (drought prone) and others (uplands). The first four were used for methane study as uplands have little or no contribution to methane emission. Delineation of deep-water stratum was not feasible. Stratification of the rice lands was carried out using the maps of rice area (Manjunath and Panigrahy, 2009, This workshop), rainfall, elevation and irrigation. All the maps were co-registered at same pixel size (1 km X 1 km), projection and coded for spatial logical analysis. The logical decision rules were applied to derive the strata. The rice strata map was also generated at 1 km X 1 km grid size.

2.2.1.1 Irrigated rice: A two-step approach has been used to delineate the wet season irrigated area. In the first step, rice area within the command area boundary was considered as irrigated. In the second step, statistical data on district level rice irrigation statistics was used to include districts that use other source of irrigation (well, tank). The above categories were merged to obtain the area under wet season irrigation. Rice crop in dry season in India are grown under either canal or ground water irrigation. Hence, total dry season rice lands have been considered as irrigated.

The irrigated strata were further categorized as:

- Irrigated (intermittent flooded - multiple aeration): Areas in the non-traditional rice belt where rice is grown in sandy/loam soil and high isolation are categorized under this (Punjab, Haryana, Rajasthan and Gujarat.
- Irrigated (continuous flooding): In this substratum, all the other irrigated area (mainly belonging to the traditional rice states) is included.

2.2.1.2 Rainfed rice: All rice areas excluding the irrigated area have been considered as rain fed. The following sub-categories were made:

- Low land (flood prone): Areas below 50 meter elevation receiving more than 1000 mm rainfall and more than 200 mm in three consecutive wet season months.
- Low land (drought prone): Areas receiving 800-1000 mm rainfall and lying in elevation range below 200 meter.
- Upland: Rest of the area was treated as Upland or categories not significant for methane emission.

2.3 In-Situ - Methane Sampling

In the present study; a stratified random sampling was used. Different sampling plan was made for wet season (kharif) rice and dry season (rabi/summer) rice. Thus, there are total five strata in kharif and only one (irrigated continuous flooding) in dry season. Since the stratum was large and more variable the sample size 'n' was determined for a given precision (var(emission)) and bound on the error of estimation assuming cost of sampling to be the same (Manjunath *et al*, 2008). The final selected sample works out approximately to about one per lakh ha. For computation of the sample size probability proportional to sampling method was used.

Field techniques for measuring CH_4 flux can be done using open and closed chambers. For reasons of cost and practicability, closed chamber techniques, also known as static chamber are almost universally employed (Hutchinson and Livingston, 1993). In the present study, the closed chamber technique (fig. 1) based on International Atomic Energy Agency (IAEA) protocol (IAEA-TECDOC-674, 1992) that has been subsequently modified by Adhya *et al.* (1994). The procedure of methane sampling from closed chamber involves covering of the crop canopy for a desired time period and measuring the subsequent increase in headspace concentration of CH_4 that is expected to be linear over time.

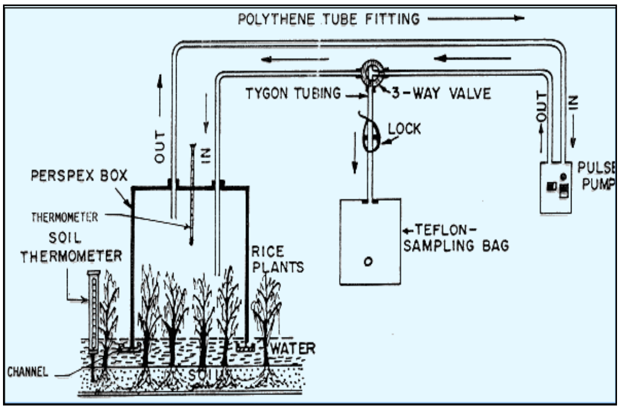

Figure 1. The Schematic Diagram Showing the Field Assembly of Methane Sampling Procedure

Since the sampling size was very large and time of sampling overlaps in many of the area there was logistical and practical difficulty in availability and procurement of large number of pulse pumps. Hence an indigenous system of air circulation was designed and developed. The chambers were fitted with two 3" fans operated by 12V battery for air circulation. The air samples collected by this method was compared and calibrated with that obtained by pulse pump method for validation. The comparison study made between the pulse pump and fan fitted samples collected indicated that the results are comparable and there was no significant difference between the two.

Methane emission varies significantly during the crop growth period. Ideally, a continuous measurement is used for understanding purpose. However, for very large area studies, generally a temporal sampling plan is used as discussed by Buendia et al, 1998. In the present study, in-situ methane emission from the fields was recorded three times during the crop growth period. The first measurement coincided with early vegetative stage (around 20 DOP -days of planting), second with peak vegetative stage (50-60 DOP) and third with soft dough stage (80-85 DOP). The methane sampling was carried out in 471 locations from 2003-2006. The weekly sampling of methane from rice field was also carried out at Central Rice Research Institute, Cuttack, Punjab Agricultural University, Ludhiana, Directorate of Rice Research, Hyderabad and farmers' fields at Srinagar, Jammu and Kashmir.

2.4 Analysis of CH4 by Gas Chromatography Technique

Gas chromatography was used to analyse the CH4 samples collected from the fields. For this, a Varian 3600 gas chromatograph (or other models) equipped with FID and Porapak N column (2 m length, 1/8 inch OD, 80/100 mesh, stainless steel column) was used. The injector, column and detector is maintained at 80, 70 and 1200C, respectively. The carrier gas (nitrogen) flow is maintained at 30 ml. min-1. One ml gas sample is injected into the gas chromatograph with a gas-tight syringe. The gas chromatograph is calibrated before and after each set of measurements using 5.38, 9.03 and 10.8 µl CH4. ml-1 in N2 (Scotty® II analyzed gases, M/s Altech associates Inc., USA) as primary standard and 2.14 µl.ml-1 in air as secondary standard. Under these conditions, the retention time of CH4 required is 0.53 min and the minimum detectable limit is 0.5 µl.ml-1. The methane flux was calculated in mg/m2/hr.

2.5 Seasonal Integrated Flux (SIF) and Deriving Methane Coefficients

The seasonal integrated flux (SIF) was calculated from the three observations made during the crop growth period for any given location. This was done by integrating the cumulative flux which was obtained by multiplying the flux at a given time with the average duration between successive observations. As given below:

$$SIF=[D_1+(D_2-D_1)/2] \text{ X } F_1+[(D_2-D_1)/2 +(D_3-D_2)/2] \text{ X } F_2 +[(D_3-D_2)/2+ (118-D_3)] \text{ X } F_3$$

where D_1, D_2 and D_3 -the days after transplanting to I, II and III flux measurements, respectively. F_1, F_2 and F_3– methane flux (Kg/ha/day) at 1st, 2nd and 3rd sampling, respectively. When the sampling was more than thrice the above formula was used to account for additional sampling periods. The methane co-efficient for each of the strata was derived using SIFs computed from the *in-situ* measurements carried out during 2003 to 2006. Total 471 site data were used for this. The strata-wise SIFs weighted mean was first calculated and then area weighted mean was obtained for a strata. Country specific as well as state specific coefficients for all the existing rice strata were derived as below:

$$W_C = \left(\sum_{i=1}^{I} SIF_C * n \right) \Big/ N$$

W_c is weighted mean of a specific strat, SIF_c is the seasonal integrated flux of a specific strata, *n* is the number of samples and N is the total number of samples within that strata.

3. RESULTS AND DISCUSSION

3.1 The Stratification of Rice Area

The state-wise wet and dry season rice area derived using SPOT VGT data of 2001-02 was 43.10 Mha. The wet season rice area was 38.53 Mha while the dry season rice area was 4.82 Mha. In the present study the rice area of India were categorized into four major strata for methane study. They are:

- IRR-I; Irrigated (intermittent flooding-multiple aeration)
- IRR-C: Irrigated (continuous flooding)
- FP: Rainfed low land-flood prone
- DP: Rainfed low land – drought prone.

Codes	IRR-C.	IRR-I	FP	DP	IRR-C (Dry Season)	Total
AP	10.4		6.1	18.0	11.7	46.2
Assam			2.7	17.5	1.2	21.4
Bihar	20.2		4.3	17.2	4.1	45.7
Guj		6.9				6.9
Har		7.6				7.6
HP				2.8		2.8
J&K	3.8					3.8
Kar	3.6		0.5	7.7	4.8	16.6
Ker	0.0		0.6	1.5	3.9	6.0
MH	2.5		1.6	15.1		19.2
MP	11.4			42.0		53.4
Orissa	9.7		6.7	19.5	1.2	37.3
PJB		21.1				21.1
Raj		1.8				1.8
TN	16.1		0.4	0.7	0.4	17.5
UP	28.2			27.1		55.4
WB	13.3		18.2	13.4	18.8	63.7
Total	119.1	37.5	41.0	182.5	46.1	426.3

Table 1: Total Rice Area Under Different Strata for the Major Rice Growing States of India Derived Using Remote Sensing and GIS (lakh ha) 2001-02

Deep-water strata could not be derived, though India has some area under deep water, especially in Assam, Bihar and West Bengal. According to IRRI report (Huke and Huke, 1997), India has 1,364 thousand ha under deep-water rice. Analysis showed that of the total rice area (all season), irrigated rice constitutes about 47.56 per cent. The irrigated rice during the dry season (irrigated-continuous flooding) occupied 10.81 per cent. During wet season the irrigated (intermittent flooding- multiple aeration) occupied 8.8 per cent and found mainly in the Punjab, Haryana, Gujarat and Rajasthan (sandy loam soil and high insolation). Irrigated (continuous flooding) occupied 27.95 per cent. The state-wise break –up of different rice strata in area is presented in table 1, respectively. The flood prone rice area is predominant in Bihar, West Bengal, Assam, Orissa and Andhra Pradesh states, while the drought prone is present in almost all the rain fed states.

3.2 Evaluation of Rice Strata

The strata map derived using RS and GIS were evaluated for accuracy by field visits in six states. The results are presented in table 2. In general an accuracy of 70% accuracy was observed. High accuracy of 79% was observed for drought prone category compared to 62.5 percent of irrigated category. The low accuracy of irrigated category stems from the fact that the crops irrigated using bore wells and other minor sources of irrigation which may not be owned by the farmer becomes difficult to be categorized as irrigated amidst large rain fed regions. A typical example of this is Madhya Pradesh and Karnataka states.

State	Details	FP	DP	IR	Total
MP	Ref.		11	7	18
	RS		11	3	14
	Acc.		100	42.9	77.8
Assam	Ref.	19			19
	RS	13			13
	Acc.	68.4			68.4
Orissa	Ref.	26	11	15	52
	RS	22	6	10	38
	Acc.	84.6	54.5	66.7	73.1
WB	Ref.	3	8	17	31
	RS	3	6	11	20
	Acc.	100.0	75.0	64.7	64.5
Bihar	Ref.	5	3	7	15
	RS	2	2	5	9
	Acc.	40	66.7	71.4	60.0
Kar	Ref.		5	10	15
	RS		5	6	11
	Acc.		100.0	60.0	73.3
Total	Ref.	53	38	56	150
	RS	40	30	35	105
	Acc.	75.5	78.9	62.5	70.0

Table 2: Accuracy Evaluation of Rice Strata

3.3 Methane Emission Pattern

The methane emission data collected at weekly interval was used to analyse the SIF. The characteristic pattern of emission of dry season crop from CRRI research fields is shown in fig. 2. The emission pattern of dry season crop of 2003, 2004 and 2005 shows a steady increase in the beginning and peaks during flowering time and further reduces gradually. The results were consistent for different varieties and across the years.

The wet season rice emission pattern during the years 2003, 04 and 05 is shown in the fig. 3 for different varieties but in the same location i.e., CRRI, Cuttack. The temporal emission pattern could be broadly put into two peaks, one during early period (before 40 days) and another during peak growth period or flowering stage. More varietal as well as seasonal/yearly variations were observed during wet season. Fig. 4 and 5 show the temporal emission pattern of methane from – Haryana, Punjab (both intermittent irrigation) and Andhra Pradesh (continuous irrigation). The Basmati rice shows higher peak than hybrid rice (PR-II) as the organic amendments are higher for Basmati rice. The zig-zag pattern of PR-II is typical emission pattern of intermittent irrigation system. The emission pattern from Punjab study site showed single peak around 35 days. The emission from Andhra state was lowest and zig-zag pattern was observed. Further studies are required to account for this pattern in continuous irrigated region.

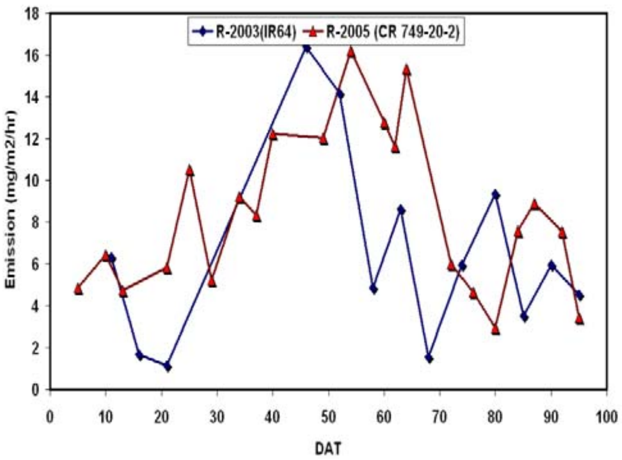

Figure 2. The Temporal Emission Pattern of Methane from Dry Season Rice Crop

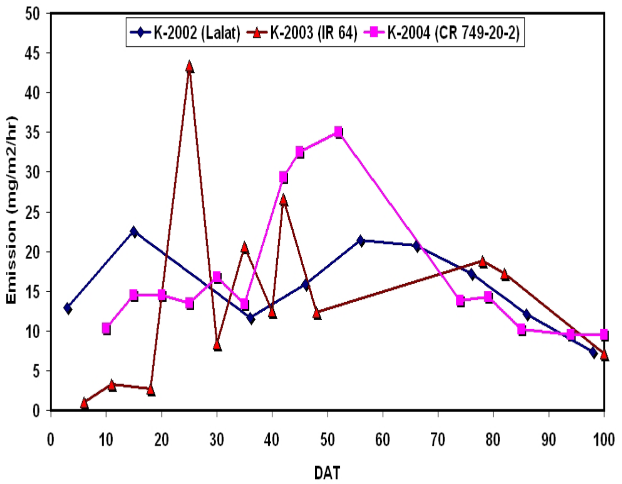

Figure 3. The Temporal Emission Pattern of Methane from Wet Season Rice Crop (CRRI, Cuttack)

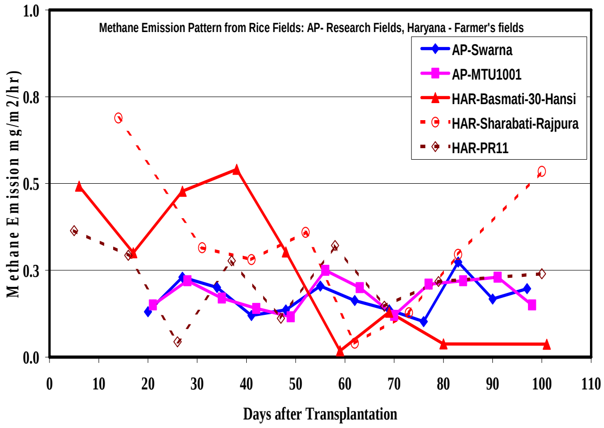

Figure 4. The Temporal Emission Pattern of Methane from Wet Season Rice Crop (Haryana and Andhra Pradesh)

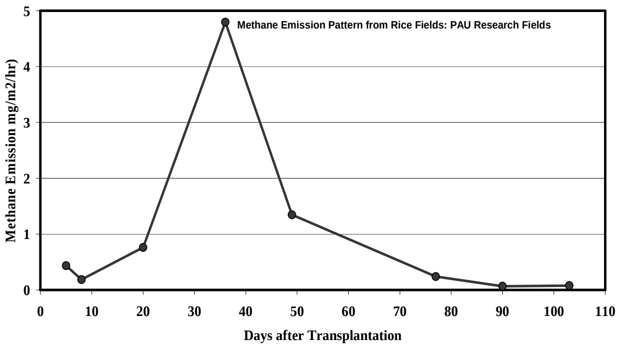

Figure 5. The Temporal Emission Pattern of Methane from Wet Season Rice Crop (Punjab 2005)

3.4 Strata-Wise Methane Coefficients

The table 3 gives the India-specific coefficients (seasonal) for different strata. The highest emissions coefficient was deep-water category 34.38±23.26 g/m^2. The samples of deep-water category are mostly from Assam state and few in Bihar state. The high emissions of deep-water rice may be attributed to long duration of rice crop coupled with high organic matter/substrate found in the region. The IRR-I strata has 5.5±2.55 g/m^2, IRR-C has 7.51±5.68 g/m^2. The dry season IRR-C has 7.83 ±3.33. The high SD of IRRI-C (kharif) shows the large variability of this stratum in terms of water regime. The FP strata have the seasonal coefficient of 13.78 g/m^2 and SD of 5.07 g/m^2.

The diverse rice growing conditions across states was reflected in the emission coefficients. The high variation of coefficients within a category across state suggests that very high diversity within a crop-growing season that could have stemmed from varieties, organic matter amendment, varying level and duration of water, etc. The current estimates are based on about 471 field observations from farmers' fields with the aim of generating a very near realistic inventory. The comparative evaluation shows that the coefficients obtained during the current study are slightly lower than other studies while irrigated-intermittent coefficient is slightly higher. The SDs of most of these are higher than the reported because of more number of samples which spread over large area unlike the other studies which were mostly limited to research stations and controlled conditions. Since the current coefficients are based on large sample size ‘n’ (471) the results are more realistic albeit higher SDs. The single emission coefficient derived from all categories and all samples (n=471) weighted for the Indian rice crop was 74.05 ± 43.28 kg/ha.

Category	Irri-cont.	Irr-int.	Flood prone	Drought prone	Deep Water	Irri-cont (Rabi-summer)	IRR-C(wet+Dry)#
MEAN	7.51	5.50	13.78	6.24	34.38	7.83	7.64
SD	5.68	2.55	5.07	5.02	23.26	3.33	5.59
n	178	87	60	62	10	74	252

Table 3: Methane Emission Coefficients of Different Rice Strata (g/m^2)

 # the coefficient for irrigated category was obtained by pooled samples of irrigated rice of both wet and dry seasons.

CONCLUSION

Agriculture accounts for approximately one-fifth of the annual increase in anthropogenic greenhouse gas emissions and rice cultivation has been accredited as one of the most important source of anthropogenic methane. The current study has developed remote sensing based technique for deriving IPCC compliant rice categories in spatial form. The results indicate that irrigated rice constitutes about 47.56 per cent. The irrigated rice during the dry season (irrigated-continuous flooding) occupied 10.81 per cent. During wet season the irrigated (intermittent flooding- multiple aeration) occupied 8.8 per cent. Irrigated (continuous flooding) occupied 27.95 per cent. The accuracy of 70% accuracy was observed for remote sensing derived rice cultural types during the evaluation exercise spread over 150 locations across the country. A wide variation in spatio-temporal pattern in methane emission was observed even within the same cultural types of rice. The CH_4 emission pattern of irrigated crop in dry season showed a steady increase in the beginning which peaks during flowering stage, decreasing gradually there after. The results were consistent for different varieties and across the years. The mean emission coefficient of strata belonging to Irrigated (cont), Irrigated (int), Rain fed (Flood prone), Rain fed (drought prone) and Deep Water is 7.51, 5.50, 13.78, 6.24, and 34.38 kg/ha, respectively. The main outcomes of the study are IPCC compliant rice categories map and country specific methane co-efficients. The outputs are very much useful for emission inventory, modeling and mitigations purposes.

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