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RESEARCH ARTICLE

GLOBAL WARMING POTENTIAL (GWP) UNDER CONVENTIONAL FLOODED RICE – RICE AND FUTURISTIC MAIZE – RICE CROPPING SYSTEMS IN CAUVERY DELTA ZONE, TAMIL NADU, SOUTH INDIA

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ABSTRACT

On a global basis, the combined agricultural emissions of Nitrous oxide (N_2O), carbon dioxide (CO_2), and methane (CH_4) account for about 20% of the annual increase in radiative forcing of climate change. Quantification of these gas emissions from soil is difficult because of their large spatial and temporal variability. Field experiments were carried out at Tamil Nadu, South India during 2010-2011 quantifies the green house gas (GHG) emissions from conventional flooded rice – rice and futuristic maize – rice cropping systems with minimum tillage. Futuristic system reduced seasonal methane emission in *rabi* rice by ten times (66.6 to 6.5 kg CH_4 ha^{-1}) as compared to conventional rice-rice system. Significant amounts of N_2O emission were also observed during the early stage of the *kharif* rice under conventional system (9.98 kg N_2O ha^{-1}) that might probably due to nitrate accumulation from previous black gram crop. Seasonal N_2O emission in maize increased from 2.47 to 8.07 kg N_2O $ha^{-1}$with increasing N levels from 0 to 300 Kg N ha^{-1}. The CO_2 emissions measured were only from dark respiration since opaque chambers were used. It was only in the maize plots that significant CO_2 emissions were detected. The CO_2 emission rates were higher at initial stage of crop growth with maximum rate of 10066 mg m^{-2} d^{-1}. Overall, the annual Global Warming Potential (GWP) was found to be three times higher in conventional system (6289 CO_2 equivalents ha^{-1} yr^{-1}) as compared to futuristic system (1944 CO_2 equivalents ha^{-1} yr^{-1}). In both systems, GWP was higher in kharif season than in rabi season. Under conventional system, GWP was 4624 CO_2 equivalents ha^{-1} in kharif and 1665 CO_2 equivalents ha^{-1} in rabi whereas under the conventional system it was 1743 CO_2 equivalents ha^{-1} in kharif and 201 CO_2 equivalents ha^{-1} in rabi. System rice equivalent yield increased by around 58% under the futuristic as compared to the conventional system mainly due to better rice yields during *rabi* rice under the futuristic as compared with the conventional system.

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INTRODUCTION

Nitrogen (N) is the major nutrient that most frequently limits rice production. In rice, it takes about 1kg of N to produce 15-20 kg of grain, but efficiency of N use in India is very low. Nitrogen is the primary driver for modern agricultural production. However, Nitrous oxide emissions from nitrogen fertilizer application have become one of the outstanding environmental global concerns of our time. On a global basis, the combined agricultural emissions of Nitrous oxide (N_2O), carbon dioxide (CO_2), and methane (CH_4) account for about 20% of the annual increase in radiative forcing of climate change (Cole *et al*., 1997). N_2O and methane CH_4 are the most potent greenhouse gases (GHG), with global warming potential of 298 and 25 times that of CO_2, respectively (IPCC 2007).

Methane

Methane (CH_4) is a radiatively active trace gas which is present in the atmosphere and is 30 times more efficient than CO_2 in trapping heat (Ramanathan *et al.,* 1985). Methane emission will have 25 times the impact on temperature of carbon dioxide emission of the same mass in the next 100 years (IPCC, 2001). US-Environmental Protection Agency, 1991 confirmed that current atmospheric concentration of CH_4 is around 1.72 ppm, but it is predicted that until the year 2100, CH_4 levels may raise to 3-4 ppm which may have a significant effect on global warming.

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The increase of CH_4 in the atmosphere contributes to global warming and affects chemical changes in the atmosphere (GEIA, 1993; Khalil and Shearer, 1993; IPCC, 1996; Cicerone and Oremland, 1988). It affects the chemistry and oxidation capacity of the atmosphere (Bolle *et al.,* 1986; Rasmussen and Khalil, 1986; Thompson and Cicerone, 1986). IPCC, 1992 declared that the CH_4 concentration in the atmosphere has doubled during the last 200 years. Methane (CH_4) production in flooded rice soils is a microbiological process affected by many biochemical and physical factors in the environment. Soil properties, water management, organic amendment, and temperature have been reported as the major factors controlling the amount of CH4 emitted from rice fields (Schuetz *et al.,* 1989; Sass *et al.,* 1991). It has also been reported that rice plants take an active part in CH4 production, oxidation, and transportation (Holzapfel-Pschorn *et al.,* 1985; Neue *et al.,* 1997; Schuetz *et al.,* 1989; Seiler *et al.,* 1984). Huke and Huke, 1997 notified that India is an important rice-producing country, comprising 28.6% of world rice area.

Nitrous Oxide

Nitrous oxide (N_2O) with its current concentration of 311 ppm in the atmosphere is an important greenhouse gas accounting for approximately 5% of the total greenhouse effect (Watson *et al.,* 1996). Among greenhouse gases, N_2O is about 310 times more capable to trap heat than carbon dioxide on a molecular basis (De Datta and Buresh, 1989). Agricultural soils contribute 65% of anthropogenic N_2O emission (6.3 Tg y^{-1}) (Mosier *et al.,* 1998). The concentration of N_2O in the atmosphere has been increasing during the last few decades at an accelerated rate. Natural and agricultural soils are considered as the most important sources of N_2O, with estimated global emissions of 6.0 and 4.2 Tg N_2O–N $year^{-1}$, respectively (IPCC, 2001). Nitrous oxide is mainly produced from two key processes: (1) aerobic autotrophic nitrification, the stepwise oxidation of ammonia (NH_3) to nitrite (NO_2) and to nitrate (NO_3) (Kowalchuk and Stephen 2001); (2) anaerobic heterotrophic denitrification, the stepwise reduction of NO_3 to NO_2, nitric oxide (NO), N_2O and ultimately N_2, (Knowles 1982). Nitrous oxide is produced from soil processes as an intermediate product of microbial nitrification and denitrification (Granli and Bockman, 1994).

Carbon dioxide

Carbon dioxide is the most important anthropogenic greenhouse gas which leads to an increase in atmospheric temperature and continues to heat for decades to centuries. It represented 77% of total anthropogenic greenhouse gas emissions in 2004. Although carbon dioxide is not a powerful greenhouse gas but it plays major role in greenhouse effect. Carbon dioxide is the sole source of carbon used by all plants during photosynthesis. Photosynthesis is a process by which plants use sunlight, water, and carbon dioxide to produce carbohydrates and other biological compounds, which reduces the amount of carbon dioxide in the air. This, in turn, helps reduce global warming. Thus plants behave as the" lungs of the Earth". The efficiency of carbon dioxide assimilation in rice, a C_3 plant, would be diminished by photorespiration. If the efficiency of carbon dioxide assimilation is increased, the amount of fixed carbons in rice increases and hence lowers the concentration of carbon dioxide in the atmosphere (Hsu *et al.* 2009). There is a lack of uniformity over the selection of direct and embodied emissions. Direct emissions are those that are made directly during the progress of a process. As an example, CO_2 released during combustion in a gasoline fired industrial boiler is a direct emission. On the other hand in electrically heated boiler, no direct emissions will be observed. But if the electricity used in the boiler was generated in a thermal power plant, the amount of CO_2 released in generation and transmission of the units of electricity consumed in the boiler is referred as the embodied or indirect emission. The atmospheric concentration of CO_2 has risen nearly 25% in the past century (Matthews *et al.* 2008b).

Green house gas emission

The experiments were carried out at 'E' Block of Tamil Nadu Rice Research Institute which is under the Cauvery delta zone of Tamil Nadu (11° N, 79.3° E) from 2009-2010. The soil of the experimental field was clayey in texture. The total nitrogen is low (0.075 %), while the available phosphorus (18.34 mg per Kg of soil) and available potassium (311.4 mg per Kg of soil) were medium. The experiment was laid out in split plot design with two main plots and four sub – plots replicated thrice: The main plot and sub plot were comprised of cropping systems (conventional and futuristic) and nitrogen levels (0, 75, 100 and 200 % of locally recommended N rate), respectively. A plot size of 30 m^2 (6m x 5m) was followed for each treatment. The experimental field was initially ploughed 6 days before transplanting with a tractor drawn cultivator and then puddled with a tractor drawn cage wheel. The field was leveled with a wooden plank before layout formation for conventional and for futuristic (maize) the experimental field was not ploughed. The furrows were just scrapped after the seed germinated at around 6 DAS. Futuristic (rice) the experimental field was digged by a spade for reduced tillage.

Static chamber

Mosier (1989) reviewed the key issues related to chamber techniques for gas flux measurement. Gas flux was measured by static chambers deployed on the soil surface. There are two parts in static chamber: the anchor or base and the moveable chamber. Anchor is made up of thin-walled stainless steel to minimize physical disturbance upon insertion. The round base (for rice field) diameter and height is 44.6 cm and 24 cm respectively. The rectangular one (for maize field) is 26.7 cm length, 22.4 cm width and 17 cm height. There are two chambers namely round and rectangular. Area occupied by round chamber for measuring plant-mediated emissions is 1562 cm^2. The Area of rectangular chamber for measuring emissions from soil is 598 cm^2. The chambers were fabricated with non-reactive materials and it is painted with white paint. It has two ports one for air thermometer and another one for gas sampling. Polypropylene syringe of 50 ml capacity with 22 gauge needle were used for gas sampling. Glass vials of 30 ml capacity sealed with crimped grey butyl rubber stoppers were utilized for storing the gas samples. A vacuum pump was used to evacuate the vials.

Gas chromatograph (GC)

A Gas chromatograph (GC) Varian 450 equipped with three different detectors was used for analysis of CH_4, N_2O and CO_2. The thermal conductivity detector (TCD) was used for analysis of $CO_{2,}$ electron capture detector (ECD) for N_2O and flame ionization detector (FID) for CH_4.

The carrier gases used were Helium with a flow rate of 60 ml/min, for TCD and FID, and Argon + 5% methane with a flow rate of 60 ml/min for ECD. The columns used for CO_2 and CH_4 analyses were Hayesep N 80/100 and Porapak QS 80/100, while that for N_2O was Hayesep N 80/100 and Hayesep D 80/100. Detector temperature settings were 200ºC for TCD, 300ºC for FID and 350ºC for ECD.

Gas sampling

Anchors were installed at 10 cm into the ground at least 24 hours prior to first flux measurement and it was packed well around the sides. Chamber was kept upside down upon the base at time of gas sampling. Fluxes were measured by determining the rate of change of trace gas concentration in the chamber headspace. Fifty ml samples were removed and transferred to previously evacuated 30 ml glass vials. Excess gas was injected into the evacuated vial to produce an overpressure. This overpressure facilitates the subsequent removal of gas sample for analysis and ensures no dilution of the samples gas inside the vial. Samples were analyzed using the Varian 450 gas chromatograph (GC) as soon as possible after collection.

Estimation of GHG emission rates

The measured gas concentration in ppm, by GC, was converted to µmole GHG L^{-1} using the gas law constant (0.08206 L atm $mole^{-1}$ $^{o}K^{-1}$) and actual temperature during the time of gas sampling (T) as given below

$$\mu mole\ GHG\ L^{-1} = ppm\ GHG / [0.08206 * (273 + T)^{o}K]$$

The emission rate (µmole GHG L^{-1} min^{-1}) was then determined from the slope of the GHG concentration in µmole GHG L^{-1} plotted against time in minutes by regression analysis. The emission rate was considered as 0 if the slope given by regression analysis was not significantly different from 0. The GHG emission rate was converted into mg GHG m^{-2} d^{-1} as given below

$$mg\ GHG\ m^{-2}\ d^{-1} = \mu mole\ GHG\ L^{-1}\ min^{-1} * V * MW * 60 * 24 * 10 / A$$

where:

T is the temperature inside the chamber in ºC
V is the total headspace volume in liters (L)
MW is the molecular weight of the GHG
A is the surface area covered by the chamber

Seasonal GHG emissions were estimated from the sum of daily emission rates. Daily emissions in-between weekly measurements were extrapolated from the average of two consecutive weekly measurements. The statistical analysis system (SAS) mixed procedure version 9.1 (SAS Institute, 2002) was used to test for treatment effects and for obtaining the standard errors of means. Pairwise mean comparisons were done using the Tukey test. Linear regression analysis was done to determine the change in GHG concentration over time and to test if the measured change is significantly different from 0. The 95% confidence intervals of seasonal GHG emissions were calculated as the mean ± 2 x standard deviation.

Estimation of Global Warming Potential (GWP)

The CH_4 and N_2O emissions were converted to GWP in units of CO_2 equivalents by multiplying CH_4 and N_2O emissions by 25 and 298 respectively. These values are the GWPs of CH_4 and N_2O relative to CO_2 for a 100-yr time horizon (IPCC, 2007).

Data Analysis

The statistical analysis system (SAS) mixed procedure version 9.1 (SAS Institute, 2002) was used to test for treatment effects and for obtaining the standard errors of means. Pairwise mean comparisons were done using the Tukey test. Linear regression analysis was done to determine the change in GHG concentration over time and to test if the measured change is significantly different from 0. The 95% confidence intervals of seasonal GHG emissions were calculated as the mean ± 2 x standard deviation.

RESULTS AND DISCUSSION

Global warming potential (GWP) under the conventional rice-rice and futuristic maize – rice management system

Although soil CO_2 fluxes also represent a source of GHG emissions, CO_2 was not included in estimating total GWP, since it is largely offset by high rates of net primary productivity and atmospheric CO_2 fixation by crop plants. On a global scale, it was estimated that CO_2 contributes less than 1% to the GWP of agriculture (Smith *et al*., 2007). Therefore, only CH_4 and N_2O were considered in the estimations of GWP under the conventional and futuristic scenarios. The annual GWP was found to be three times higher in conventional system (6289 CO_2 equivalents ha^{-1}) than in futuristic system (1944 CO_2 equivalents ha^{-1}) mainly due to the high methane emissions plus the N_2O emissions in karif rice which was preceded by black gram under the conventional system (Fig. 9). The CH_4 emissions during karif and *rabi* under the conventional management were very similar. Elimination of puddling (futuristic system) reduced the methane emission and subsequently the GWP under the futuristic system. (Table 1) Results and discussion

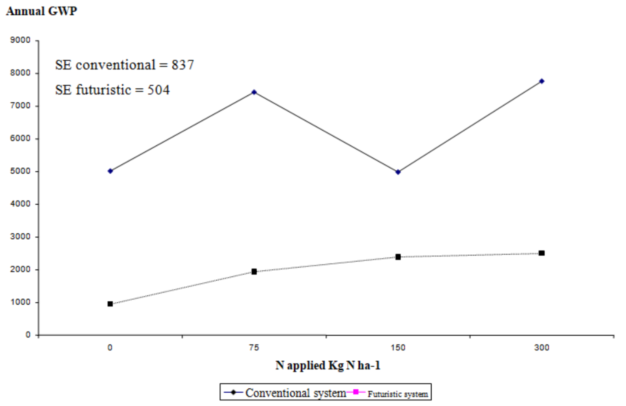

Fig. 1. Annual global warming potential (GWP, CO2 equivalents ha-1) under the Conventional and futuristic management system

Global warming potential (GWP) under the conventional rice-rice and futuristic maize – rice management system

Although soil CO_2 fluxes also represent a source of GHG emissions, CO_2 was not included in estimating total GWP, since it is largely offset by high rates of net primary productivity and atmospheric CO_2 fixation by crop plants. On a global scale, it was estimated that CO_2 contributes less than 1% to the GWP of agriculture (Smith *et al*., 2007). Therefore, only CH_4 and N_2O were considered in the estimations of GWP under the conventional and futuristic scenarios.

Table 1. Estimates of global warming potential (GWP, CO_2 equivalents ha^{-1}) under the conventional rice-rice management scenario

N applied Kg N ha^{-1}	*Kharif* Rice					*Rabi* Rice			Annual GWP
	N_2O		CH_4		*Kharif* GWP	CH_4		*Rabi* GWP	
	Kg N_2O ha^{-1}	GWP	kg CH4 ha^{-1}	GWP		kg CH_4 ha^{-1}	GWP		
0	7.04	2098	40.8	1019	3117	75.9	1899	1899	5016
75	8.75	2609	126.3	3157	5766	66.6	1664	1664	7430
150	8.38	2498	52.8	1321	3819	46.7	1167	1167	4986
300	15.60	4650	47.5	1187	5837	77.1	1927	1927	7764
SE of N means	1.83	545	6.4	160	568	24.6	615	615	837
Season Means	9.94	2962	66.8	1662	4624	66.6	1665	1665	6289
SE of season means	1.26	375	3.39	85	384	12.49	322	322	501

Table 2. Estimates of global warming potential (GWP, CO_2 equivalents ha^{-1}) under the futuristic maize-rice management scenario

N applied Kg N ha^{-1}	*Kharif* Maize			*Rabi* Rice					Annual GWP
	N_2O		*Kharif* GWP	N_2O		CH_4		*Rabi* GWP	
	Kg N_2O ha^{-1}	GWP		kg N_2O ha^{-1}	GWP	kg CH_4 ha^{-1}	GWP		
0	2.47	735	735	0.05	13.6	7.9	197	211	946
75	5.04	1503	1503	0.30	87.8	14.0	349	437	1940
150	7.81	2329	2329	0.07	21.2	1.6	39	60	2389
300	8.07	2406	2406	0.08	25.0	2.7	67	92	2498
SE of N means	1.61	480	480	0.08	24.4	6.06	152	154	504
Season Means	5.85	1743	1743	0.124	37.0	6.55	164	201	1944
SE of season means	1.34	399	399	0.05	14.9	3.03	76	77	406

Table 3. Grain yields over three seasons at 4 N levels

	Grain yield in kg ha^{-1}						
N rates	Conventional			Futuristic			
	kharif	*rabi*	Total	*Kharif*		*rabi*	Total
	Rice	Rice	System rice yield	Maize	Equivalent rice yield	Rice	System rice equivalent yield*
0	2123	2044	4167	1903	1974	4016	5990
75	2716	2537	5253	2154	2235	6018	8253
150	2656	2634	5290	2182	2264	6404	8668
300	1921	3298	5219	1706	1770	6787	8557
SE	341	207	399	31	32	207	209

*Maize yield was converted to rice equivalent yield by multiplying by the factor price of maize / price of rice (1.037)

The annual GWP was found to be three times higher in conventional system (6289 CO_2 equivalents ha^{-1}) than in futuristic system (1944 CO_2 equivalents ha^{-1}) mainly due to the high methane emissions plus the N_2O emissions in karif rice which was preceded by black gram under the conventional system (Fig. 9). The CH_4 emissions during karif and *rabi* under the conventional management were very similar. Elimination of puddling (futuristic system) reduced the methane emission and subsequently the GWP under the futuristic system.

Effect of management system on rice, maize and system yields

The futuristic management, maize followed by unpuddled-transplanted rice, not only decreased the GWP but also increased the system yield significantly as compared to the conventional rice-rice system. It was observed that more weeds were present under the conventional system than in the futuristic system with the glyphosate treatment after maize harvest. This may have resulted in a better crop establishment under the futuristic system than in the conventional system. The net income and B: C ratio was found to be higher in futuristic system than conventional system. Therefore, this futuristic system shows potential in increasing farmers' income and also in reducing the GWP from the conventional farmers' practice. However, the time of sowing and water, needs to be well managed for the maize crop as it is very sensitive to water-logging.

Except for rice during the *kharif* season, rice, maize and system yields increased from 0 to 150 kg N ha^{-1} fertilizer N rate. In *kharif* rice 300 kg N ha^{-1} has shown lowest yield than other N rates because of severe attack of pest and disease namely mites and brown spot respectively. (Table 3)

Summary and conclusion

The annual GWP was 3 times higher in the conventional system (6289 CO_2 equivalents ha^{-1} yr^{-1}) as compared to the futuristic system (1944 CO_2 equivalents ha^{-1} yr^{-1}). A better crop establishment was observed during the rabi rice under the conventional system as compared with the futuristic system. This may be due to less weeds under the futuristic system as a result of glyphosate treatment after maize harvest. System rice equivalent yield increased by around 58% under the futuristic as compared to the conventional system mainly due to better rice yields during rabi rice under the futuristic as compared with the conventional system. The proposed maize-rice system with minimum tillage has potential to reduce the GWP of rice systems in the Cauvery delta as well as increase yields and farmers' income over the conventional rice-rice system.

REFERENCES

Bolle, H. J., W. Seiler and B. Bolin. 1986. Other greenhouse gas and aerosols. In: The Greenhouse Effect. *Climate Change and Ecosystems*, pp 157-198, New York.

Cicerone, R. J. and R. S. Oremland. 1988. Biogeochemical aspects of atmospheric methane. *Global Biogeochem Cycles* 2: 299-327

De Datta, S. K. and R. J. Buresh. 1989. 'Integrated N management in irrigated rice', Adv. Agron. 10, 143−169.

GEIA – Global Emission Inventory Activity. 1993. Report on the 3rd workshop, Amersford, 31 Jan-02 Feb 1993, A.F. Bowman (ed), Bilthoven, The Netherlands,

Granli, T. and O. C. Bockman. 1994. Nitrous oxide from agriculture. Norweg J. Agric. Sci., 12:1–128 grassland. *Nutr. Cycl. Agroecosys* 46:257–267.

Holzapfel-Pschorn, A., R. Conrad and W. Seiler. 1985. Production, oxidation, and emission of methane in rice paddies. *FEMS Microbiol Ecol.,* 31:149-158.

Huke R.E. and E.H. Huke. 1997. Rice area by type of culture: South, Southeast and East Asia. International Rice Research Institute, Los Banos, Laguna, Philippines, 15 p Bachelet D and Neue HU (1993) Methane emissions from wetland rice areas of Asia. Chemosphere 26:219-237

IPCC – Intergovernmental Panel on Climate Change. 1996. Climate Change: The Science of Climate Change. Cambridge (UK): Cambridge University Press. 572 p

IPCC – Intergovernmental Panel on Climate Change. 2006. Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventory Programme, Eggleston HS et al (Inst Glob Environ Strat, Hayama, Japan).

IPCC – Intergovernmental Panel on Climate Change. 2001. Climate change: the science of climate change (XII). Cambridge Univ. Press, Cambridge.

IPCC – Intergovernmental Panel on Climate Change. 2007. Climate change: the physical science basis. In: Soloman et al, editors. Climate change. Cambridge Univ. Press, Cambridge. p 996.

IPCC. Intergovernmental Panel on Climate Change. 2000. Good practice guidance and uncertainty management in national greenhouse gas inventories. Intergovernmental Panel on Climate Change (IPCC), Geneva, Switzerland.

IPCC—Intergovernmental Panel on Climate Change. 1992. Climate change. The supplementary report to the IPCC scientific assessment. Cambridge University Press, NewYork.

Khalil, M. A. K. and M. J. Shearer. 1993. Atmospheric methane:sources, sinks and role in global change. Chemosphere26:201-217.

Knowles. R. 1982. Denitrification. Microbiol Rev 46:43–70 Flechard CR, Ambus P, Skiba U, Rees RM, Hensen A, van Amstel A, n Dasselaar AV, Soussana J-F, Jones M, Clifton.

Kowalchuk, G.A., J. R. Stephen. 2001. Ammonia-oxidizing bacteria: a model for molecular microbial ecology. Annu Rev Microbiol 55:485–529.

Matthews, S. C., C. T. Hendrickson and C. L. Weber. 2008b. The importance of carbon footprint estimation boundaries. Environmental Science and Technology, 42(16), 5839–5842.

Mosier, A.R. 1989. Chamber and isotopic techniques. In M.O. Andreae and D.S. Schimel (eds.), Exchange of Trace Gases between Terrestrial Ecosystems and the Atmosphere, pp 175-188.

Mosier, A.R., C. Kroeze, C. Nevison, O. Oenema, S. Seitzinger, O. Van Cleemput. 1998. Closing the global atmospheric N2O budget: nitrous oxide emissions through the agricultural nitrogen cycle. Nutr Cycl Agroecosys 52:225–248

Neue H.U., R. Wassmann, H.K. Kludze, B. Wang and R.L. Lantin. 1997. Factors and processes controlling methane emissions from rice fields. Nutr Cycling Agroecosyst 49:111- 117.

Ramanathan, V., R.J. Cicerone, H.B. Singh and J.T. Kiehl. 1985. Trace gas trends and their potential role in climate change. J Geophys Res 90:5547-5566 US-Environmental Protection Agency (1991) Methane emissions and opportunities for control. EPA/400/9-90/9007, US EPA, Washington DC.

Rasmussen, R.A. and M.A.K. Khalil. 1986. Atmospheric trace gases: Trends and distribution over the last decade. Science 32:1623-1624.

SAS Institute. 2002. SAS Version 9.1. SAS Inst., Cary, NC.

Sass RL, Fisher FM, Harcombe PA and Turner FT (1991) Mitigation of methane emissions from rice fields: possible adverse effects of incorporated rice straw. Global Biogeochem Cycles 5:275-287

Schuetz, H., A. Holzapfel-Pschorn, R. Conrad, H. Rennenberg and W. Seiler. 1989. A three-year continuous record on the influence of daytime season and fertilizer treatment on methane emission rates from an Italian rice paddy field. J Geophys Res 94:16405-16416.

Schuetz, H., W. Seiler and R. Conrad. 1989. Processes involved in formation and emission of methane of rice paddies. Biogeochemistry 7:33-53.

Seiler, W., R. Conrad and D. Scharffe (1984) Field studies of methane emission from termite nests into the atmosphere and measurements of methane uptake by tropical soils. J Atmos Chem 1:171-186

Thompson, A.M. and R.J. Cicerone. 1986. Possible perturbations to atmospheric CO, CH4 and OH. J Geophys Res 91 (D): 10858-10864 IPCC – Intergovernmental Panel on Climate Change (1992).In: Houghton JT, Callander BA and Varney SK (eds) Climate Change - The Supplementary Report to the IPCCScientific Assessment, 200 p, Cambridge, UK.

Watson, R. T., M. C. Zinyowera, R. H Moss and Dokken, D. J.: 1996, Climate Change 1995, Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses, Intergovernmental Panel on Climate Change, Cambridge University Press, U.S.A., p. 879.

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