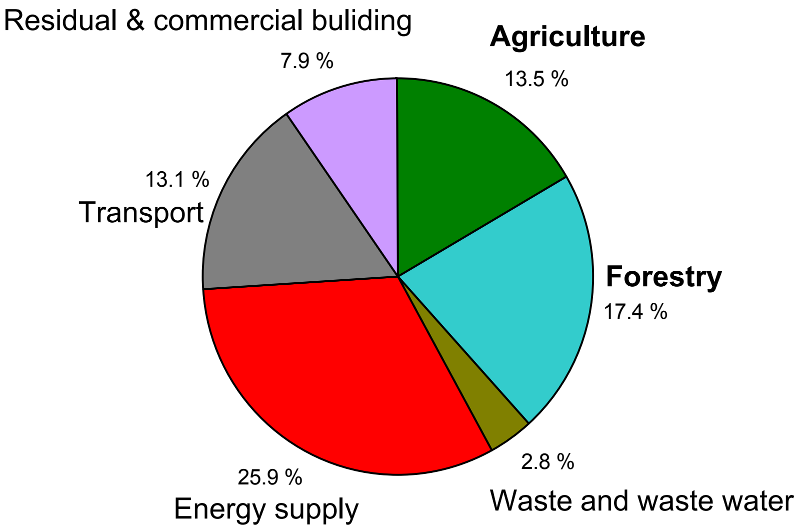
Workshop on Agriculture, Food Security & Greenhouse Gas Accounting

September 07-09, UCSD, San Diego

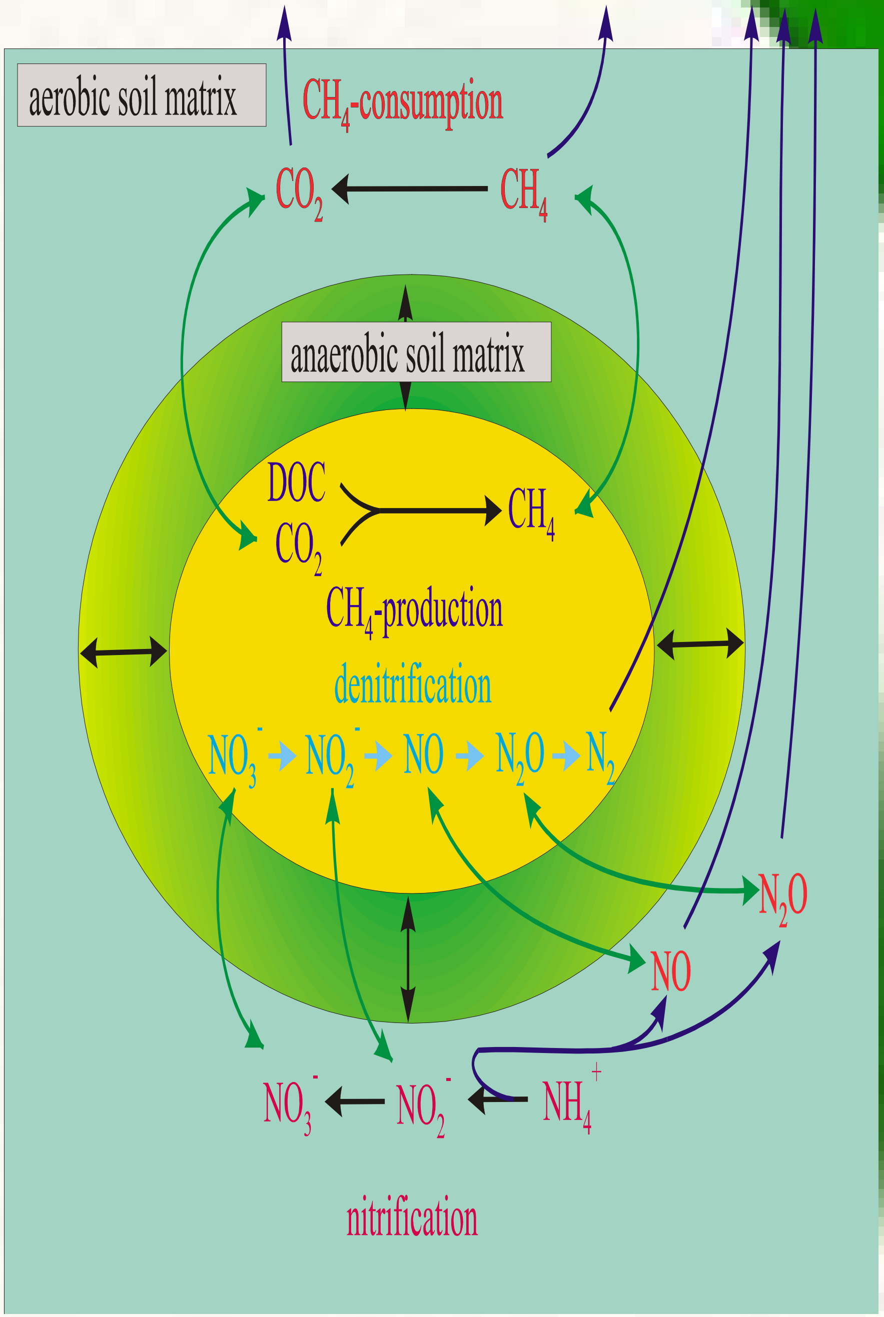
Reducing Greenhouse Gas Emission form Indian Paddy

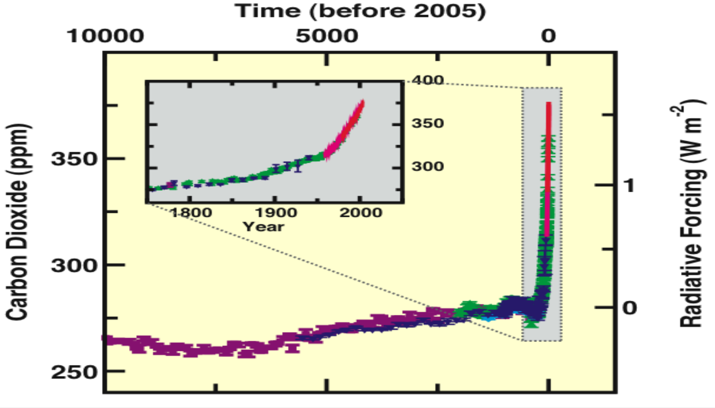
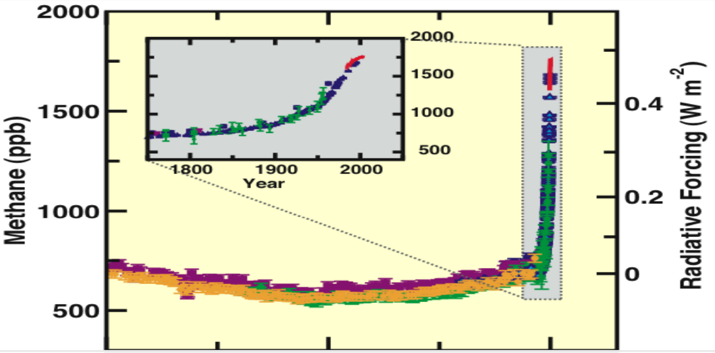
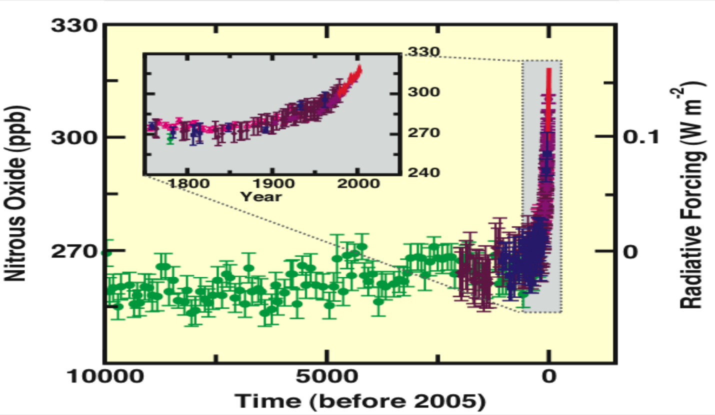
Tapan K. Adhya
Central Rice Research Institute
Cuttack 753006, India
adhyas@yahoo.com

Agriculture: A Source & Sink of GHG



Shape of different sectors in total anthropogenic GHG emission in 2004 in terms of CO_2 equivalents (source: IPCC 2007)



Gas / share of greenhouse effect		Sources
	Carbon dioxide (CO_2)	1) fossil fuel combustion 2) Deforestation 3) Biomass burning
	Methane (CH_4)	1) Livestock 2) Rice
	Nitrous oxide (N_2O)	Fertilizer

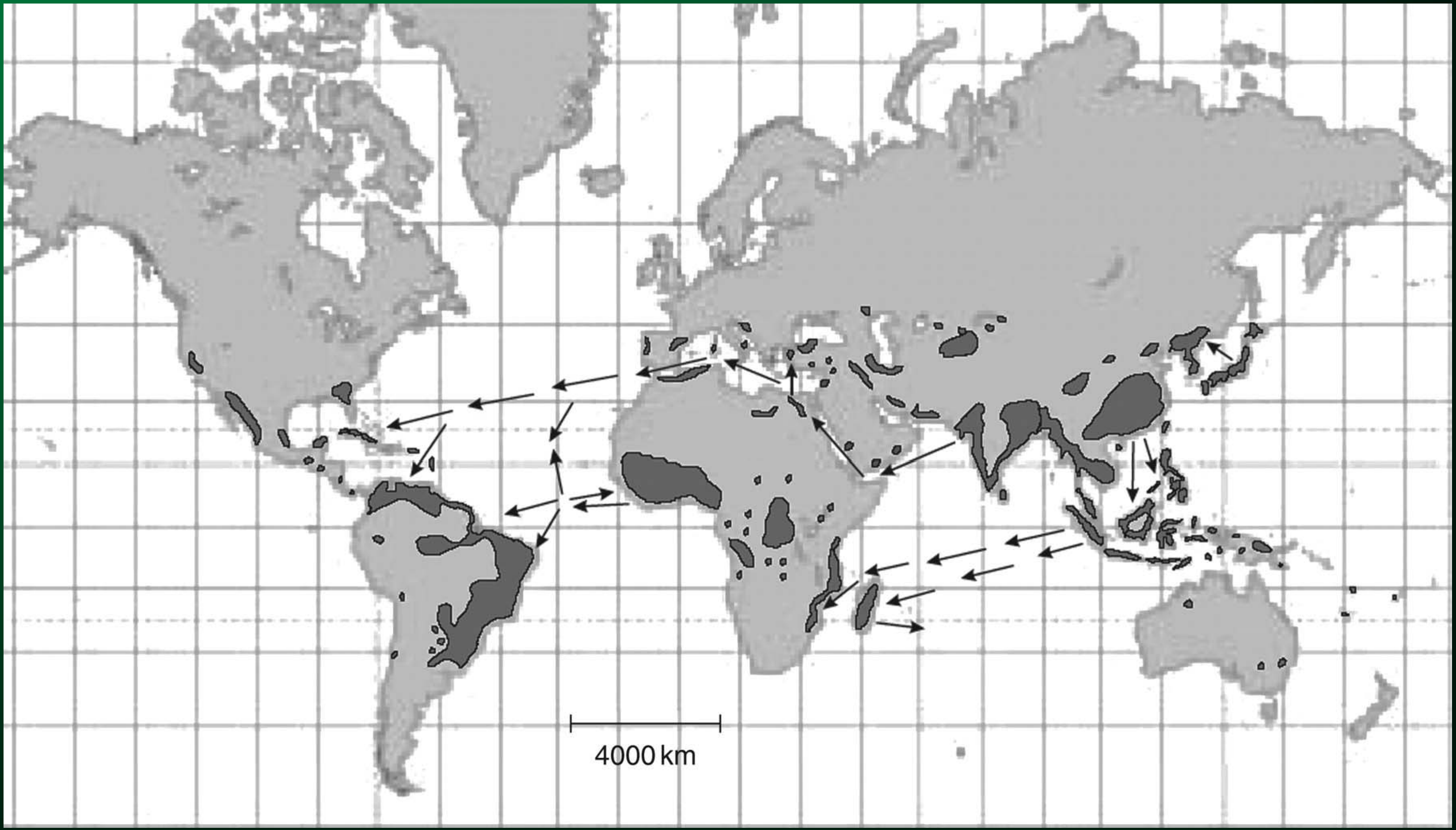
Tropical agriculture comprises an enormous variety of activities that directly or indirectly affect GHG emissions. Globally, the most significant activities identified include:

a. Deforestation for reclaiming new agricultural land as a source of CO_2.
b. CO_2 from biomass burning
c. Rice-based production systems as source of CH_4 and N_2O, and
d. Animal husbandry as a source of CH_4.

Importance of Rice (World/Asia/India)

- Global Rice area - about 153 million ha, production - about 416 million tons
- Staple food of >50% of the world population
- Accounts for 30 to 76% of the total calorie intake by more than 3 billion Asians
- More than 90% of rice is produced and consumed in Asian countries
- In India, rice contributes maximum (43%) to the total food grains production (218 million tons) followed by wheat (34%)
- Rice supplies maximum calories (30%) in the diet of Indians

Distribution and spread of rice fields around the world



Verhoeven J T A , Setter T L Ann Bot 2010;105:155-163

Upland rice

Rice ecosystems : Irrigated

Rice ecosystem : Rainfed lowland

Rice ecosystem : Deepwater rice

Rice ecosystem : Hill rice

Rice in India is grown in ~44 m ha area

Upland rice	: 7 m ha
Irrigated rice	: 16 m ha
Lowland rice	: 21 m ha

Rice production in India ~ 100 m tons

India has the credentials as a producer of raw materials

MILK
Largest Producer

TEA
Largest Producer

WHEAT
#2 in the world

RICE
#2 in the world

TRACTORS
Largest Market

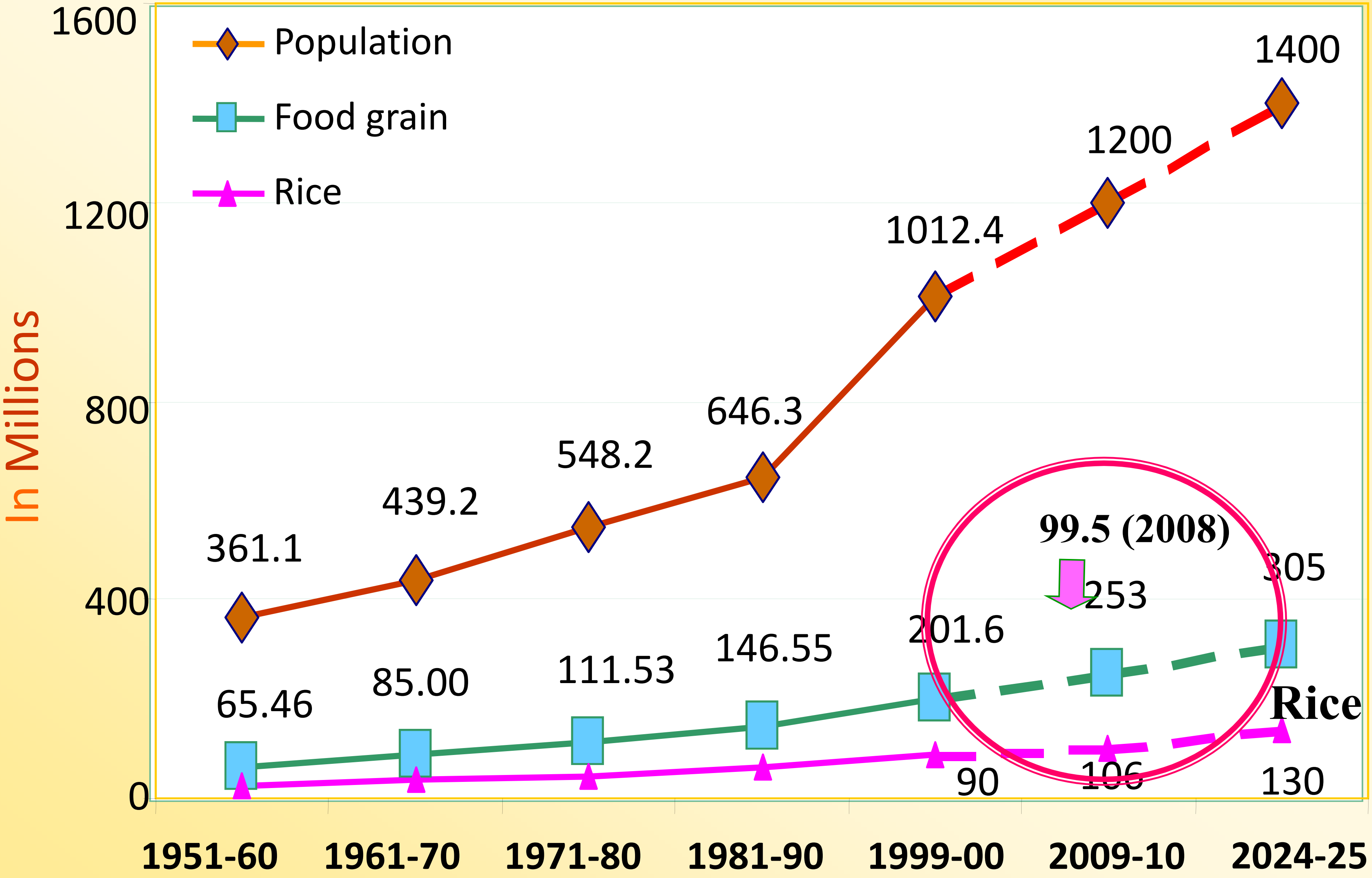
LIVESTOCK
Largest in the world

FRESH PRODUCE
#2 in the world

SUGAR
2 in the world

A NET CROPPED ARE OF 142 mn HECTARES

Population, production of food grains and rice in India : Trends and Projections



India’s initial national greenhouse gas inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by Montreal Protocol for the base year 1994

GHG Source and sink categories (Gg.yr^{-1})	CO_2 Emission	CO_2 removal	CH_4	N_2O	CO_2 eq. emission
Net National Emission	817023	23533	18083	178	1228540
Agriculture			14175	151	344485
Enteric fermentation			8972		188412
Manure management			946	1	20176
Rice cultivation			4090		85890
Agril. crop residues			167	4	4747
Emission from soils				146	45260

NATCOM 1, 2004

Important agricultural contributors to India's CO_2 equivalent GHG emissions in 2000 (Garg et al., 2004)

Source category	Main emission	Percentage share	Nature of emission
Livestock related	CH_4, N_2O	12.6	Highly dispersed
Paddy cultivation	CH_4	6.6	-do-
Biomass consumption	CH_4, N_2O	5.2	-do-
Fertilizer use	N_2O	4.1	-do-

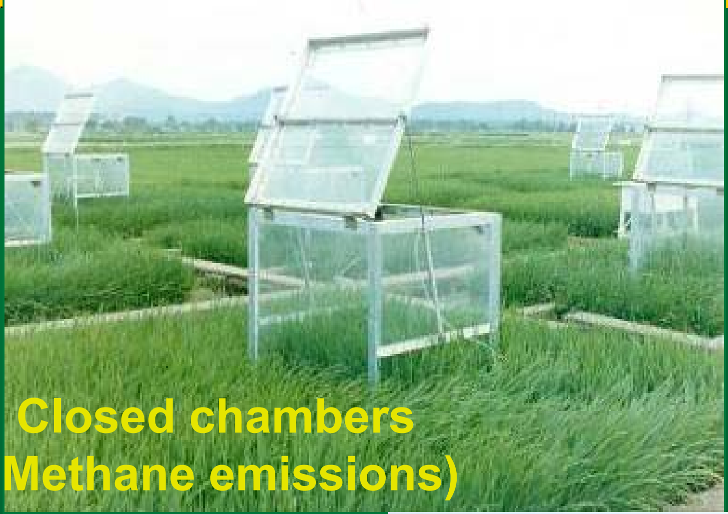
In spite of majority of Indians living in villages where agriculture is the main economic activity, agriculture including livestock and other activities contributes 29% of India's GHG emissions. GHG emissions are predominantly from urban activities.

Because of the unique nature of rice production, typically flooded soils and relatively high N input, the potential for significant emission of CH_4 during flooded periods and N_2O emissions during non-flooded periods exists. For crops grown in non-saturated/moist soils N_2O is predominant.

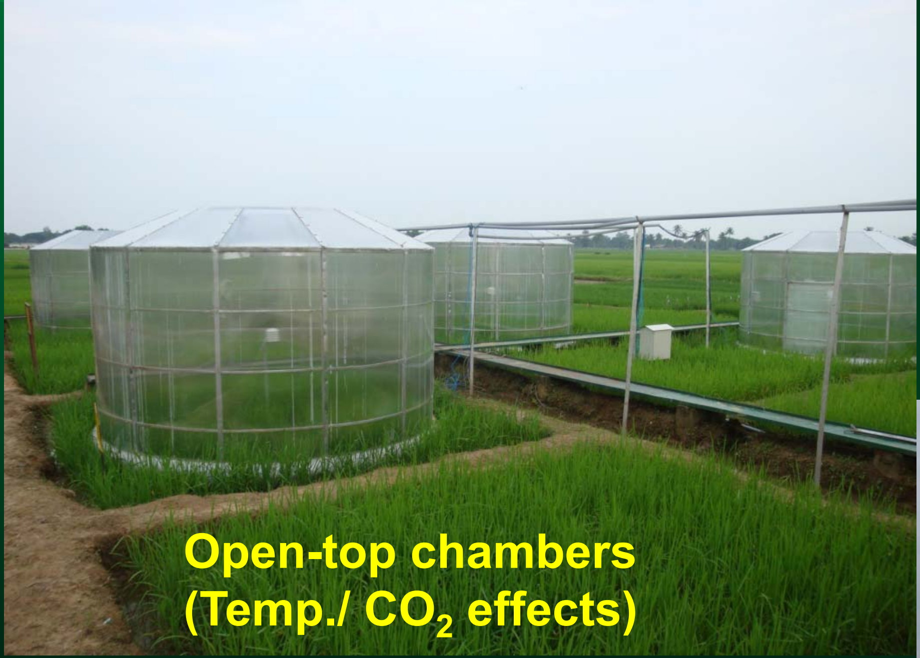
The emissions are affected by a multitude of different factors related to both natural conditions as well as crop management and can be distinguished between:

a. Primary factors that determine the level of emissions, &
b. Secondary factors that modulate emissions.

CRRI research initiatives in GHG emission study



Closed chambers
(Methane emissions)



Open-top chambers
(Temp./ CO_2 effects)

Eddy covariance
tower
(CO_2 flux)

CH_4 emission from agriculture in India (10.07 Tg)

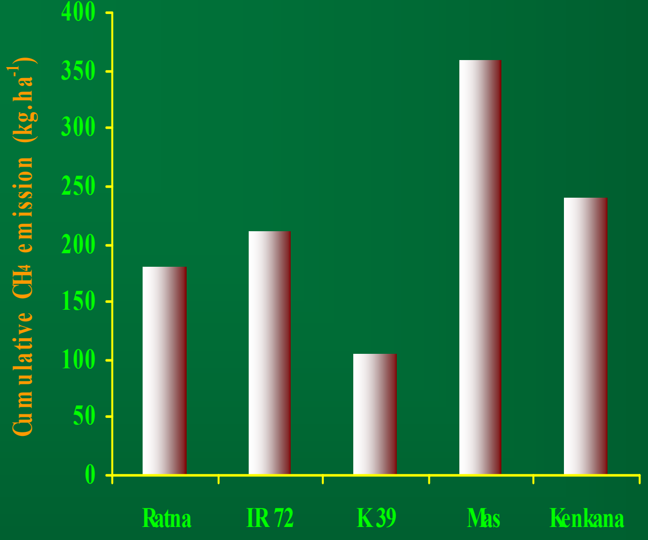
- With a total area of 44.5 m ha under rice cultivation under different ecologies, CH_4 emission may give a budget of 5 Tg Yr^{-1} for India out of a global emission of 60 to 150 Tg CH_4 Yr^{-1}.

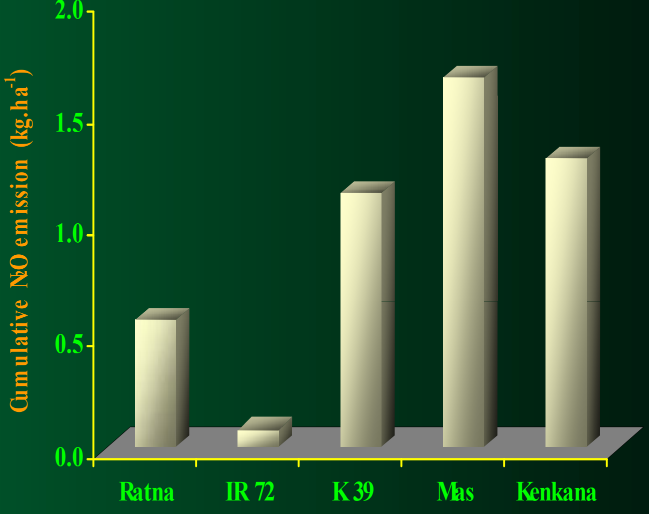
  (Nutr. Cycl. Agro-Ecosystems 64:19-31)

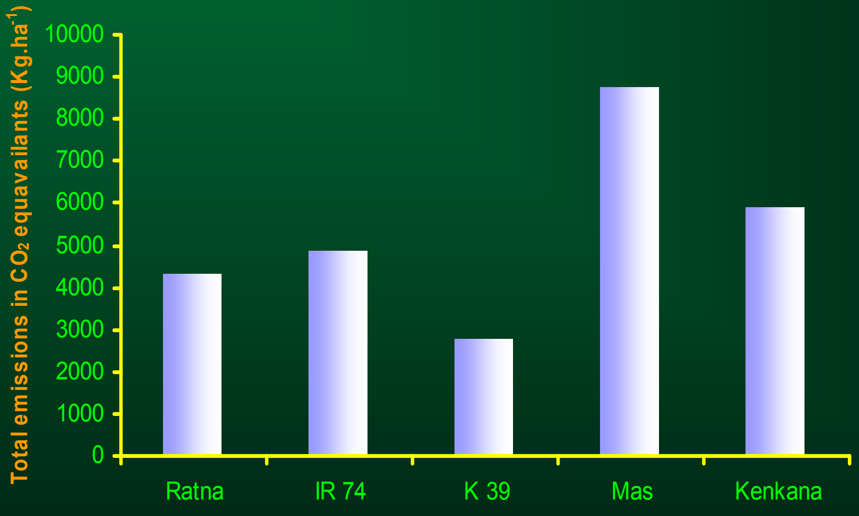
- In addition, enteric fermentation by ruminants, anaerobic waste processing and manure managements are the principal sources of CH_4 from agriculture. Among these, ruminant animals contribute the major portion.

Seasonal CH_4 and N_2O emissions (expressed as GWP) from rice field fertilized with urea or urea plus rice straw

Season	Urea		Urea + Rice straw	
	N_2O	CH_4	N_2O	CH_4
	(g CO_2-equivalent.m^{-2}.$season^{-1}$)			
Fallow	832	4.2	1420	7.7
Rice (DS)	122	296	78	5520
Fallow	2340	4.6	2350	5.5
Rice (WS)	179	907	81	9840





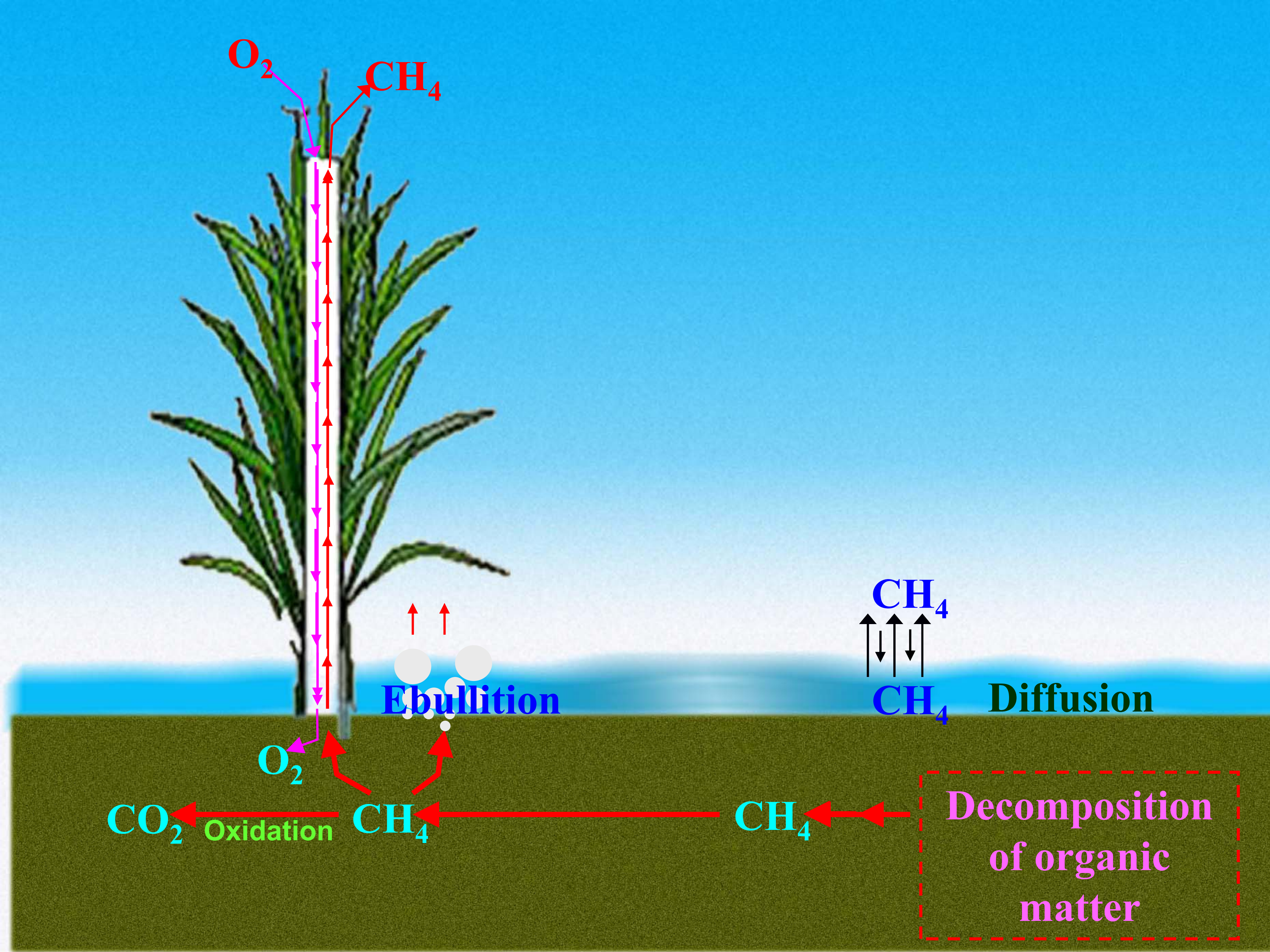


Methane and nitrous oxide efflux in select rice varieties

Plant and Soil 202 : 223-229 (1998)

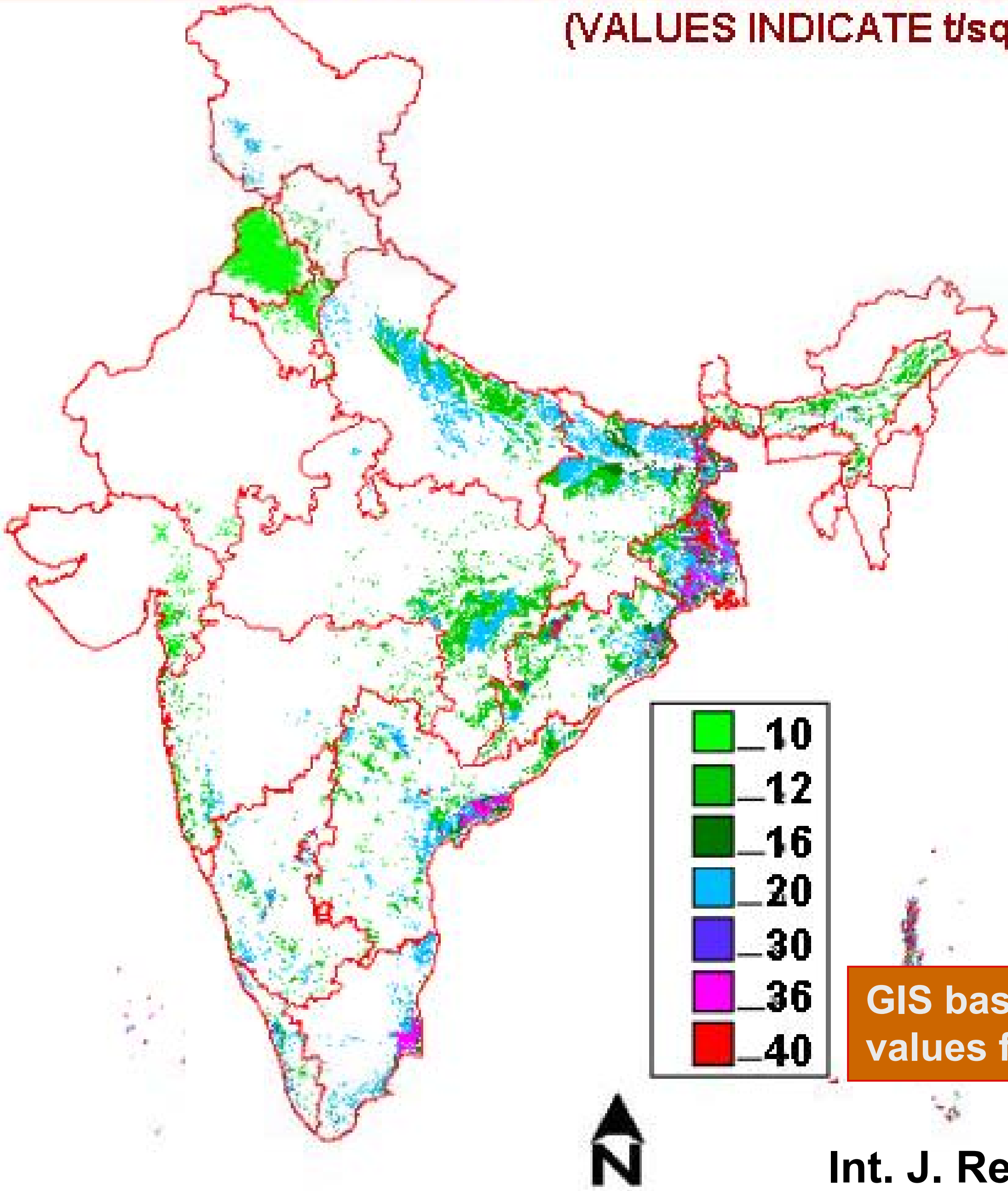
Rice plants perform Three key functions for regulating CH_4 and N_2O budget :

- source of substrate for methanogenic and denitrifying bacteria
- conduit for CH_4 and N_2O through aerenchyma, and
- provide active CH_4 oxidizing and nitrification sites in the rhizosphere by transporting O_2


O_2
CH_4
CH_4
Ebullition
CH_4
Diffusion
O_2
CO_2
Oxidation
CH_4
CH_4
Decomposition of organic matter

METHANE EMISSION MAPS OF TOTAL RICE AREA

(VALUES INDICATE t/sq.km ha)



(INC-UNFCCC, 2004)

WET SEASON	3.27 TO 5.69 Tg
	MEAN =4.48 Tg
DRY SEASON	0.82 TO 1.32 Tg
	MEAN =1.07 Tg
TOTAL	4.10 TO 7.01 Tg
	MEAN =5.55 Tg

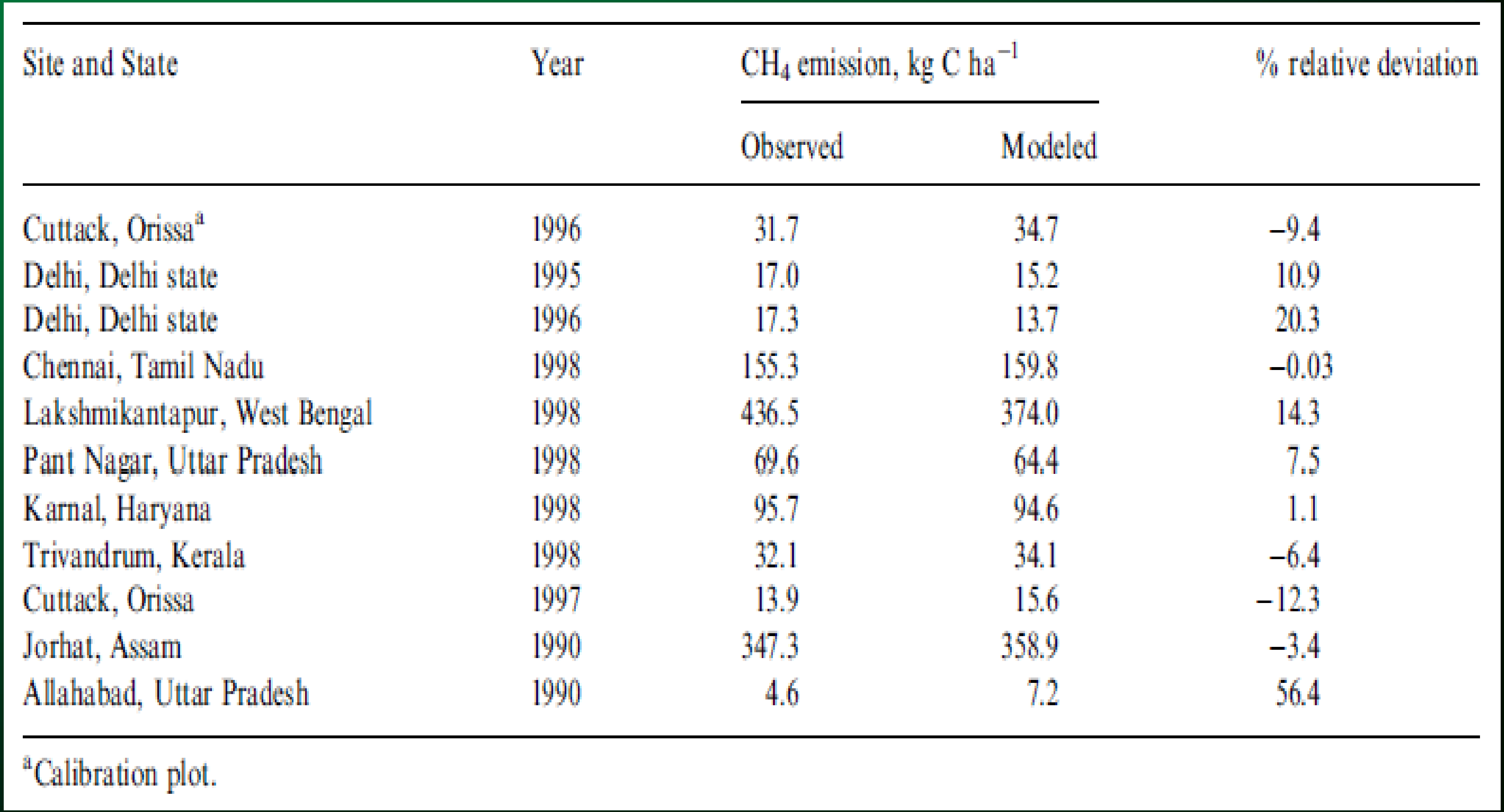
(IPCC)

WET SEASON	MEAN =5.36 Tg
DRY SEASON	MEAN =1.23 Tg
TOTAL	MEAN =6.59 Tg

GIS based placement of CH_4 emission flux values from Indian rice paddy

Int. J. Remote Sensing 27:4701-4707 (2006)

Validation of seasonal CH_4 emission from rice fields of India using DNDC model



Site and State	Year	CH_4 emission, kg C ha^{-1}		% relative deviation
		Observed	Modeled	
Cuttack, Orissa[a]	1996	31.7	34.7	−9.4
Delhi, Delhi state	1995	17.0	15.2	10.9
Delhi, Delhi state	1996	17.3	13.7	20.3
Chennai, Tamil Nadu	1998	155.3	159.8	−0.03
Lakshmikantapur, West Bengal	1998	436.5	374.0	14.3
Pant Nagar, Uttar Pradesh	1998	69.6	64.4	7.5
Karnal, Haryana	1998	95.7	94.6	1.1
Trivandrum, Kerala	1998	32.1	34.1	−6.4
Cuttack, Orissa	1997	13.9	15.6	−12.3
Jorhat, Assam	1990	347.3	358.9	−3.4
Allahabad, Uttar Pradesh	1990	4.6	7.2	56.4

[a] Calibration plot.

Nutr. Cycl. Agroecosyst. 74:157-174 (2006)

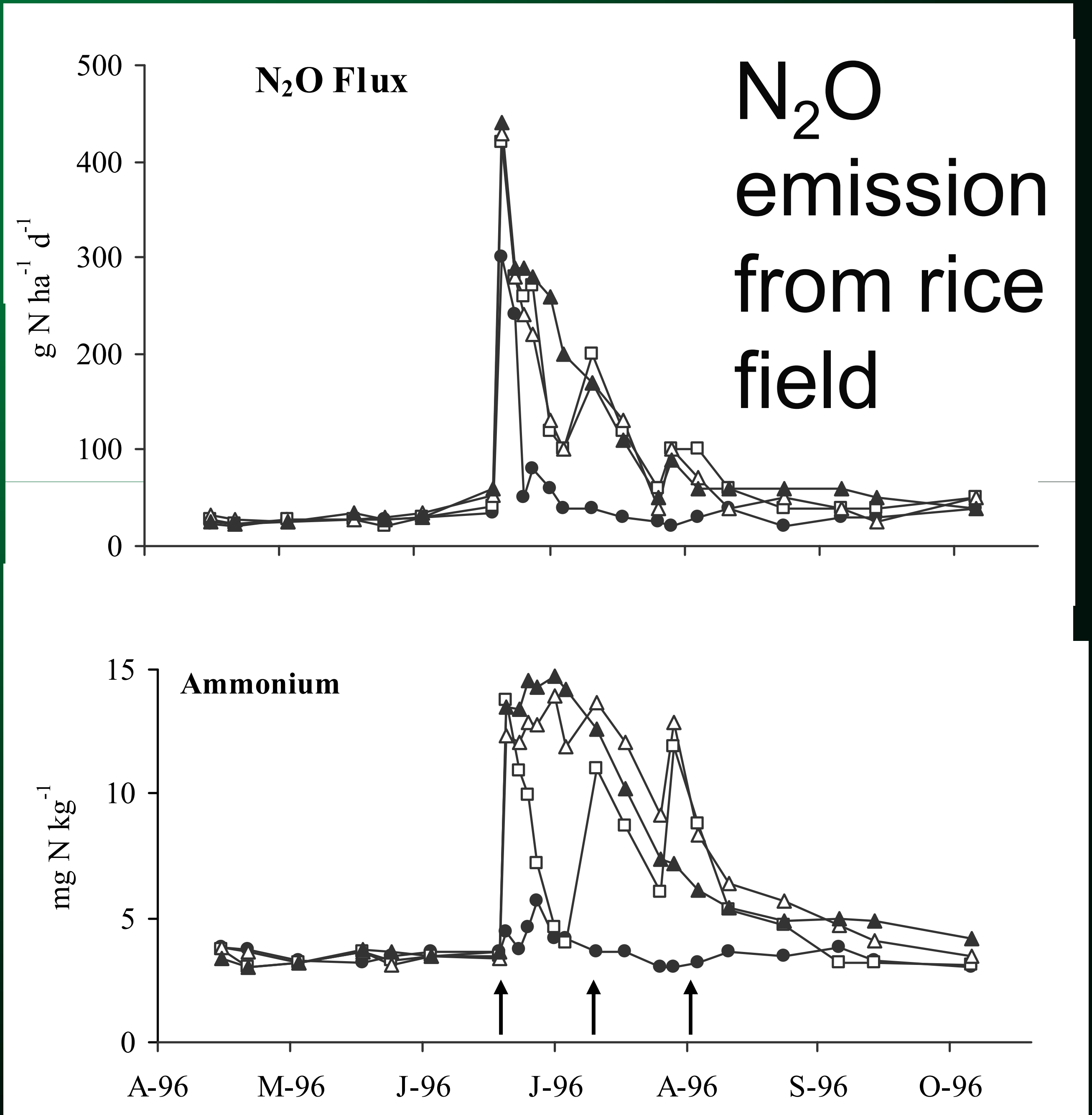
N_2O emissions in India (0.31 Tg)

- Agriculture sector activities account for more than 90% of the total N_2O emissions in India.

It includes:

- 66% from the use of chemical fertilizers,
- About 10% from field burning of agricultural residues and indirect soil emissions,
- About 5% from livestock excretions.

Use of synthetic fertilizers is the single largest source of N_2O emissions



N_2O emission from rice field

Soil and plant parameters to predict CH_4 and N_2O emission from rice agriculture

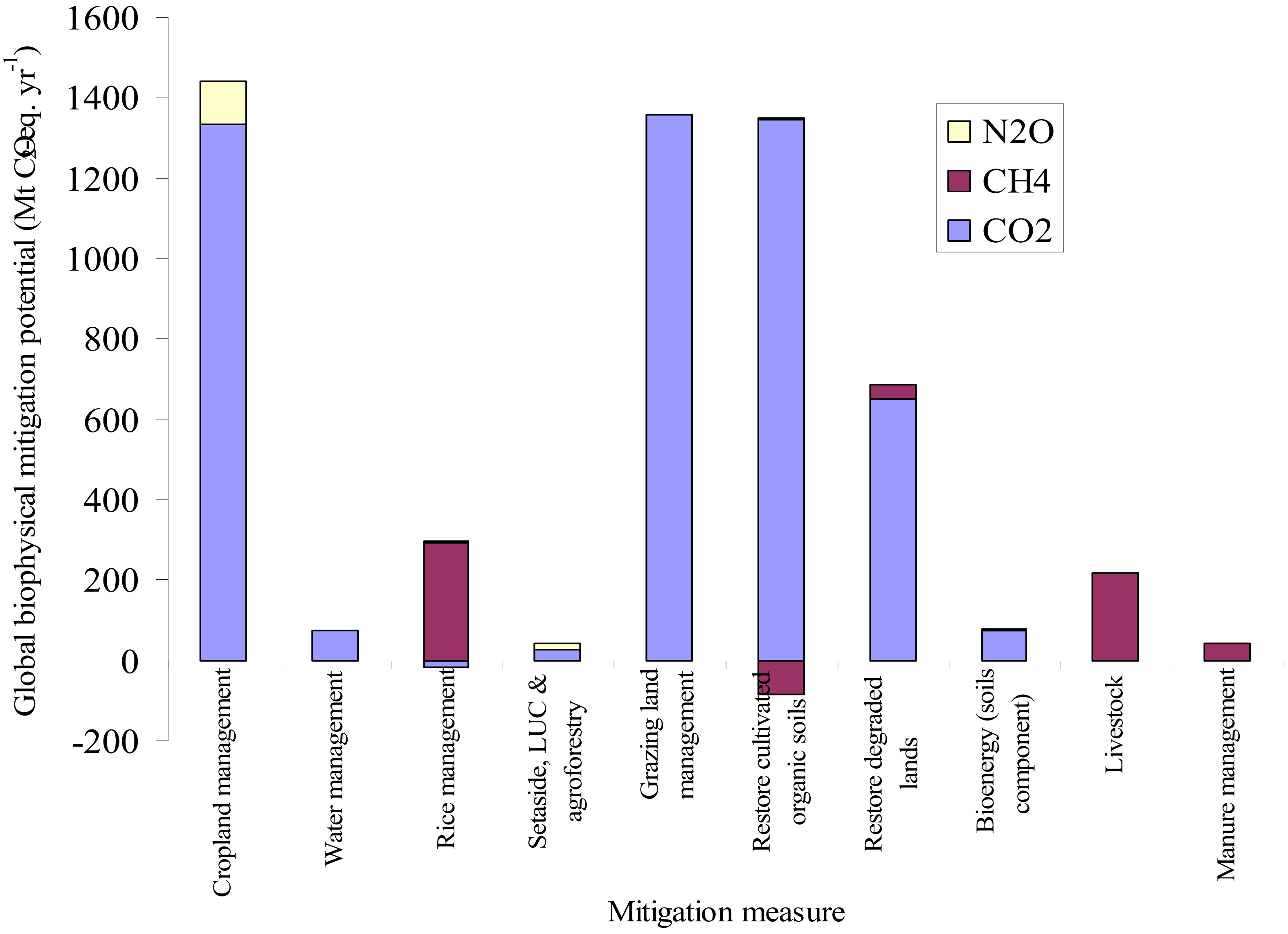
CH_4 emission is more plant related

CH_4 emission = 7.025 + 0.0036 shoot volume - 0.02 root volume ($R^2 = 0.61^{**}$)

N_2O emission, on the contrary, is more soil-related

N_2O emission = 11.163 + 1.267 silt ($R^2 = 0.508^{**}$)

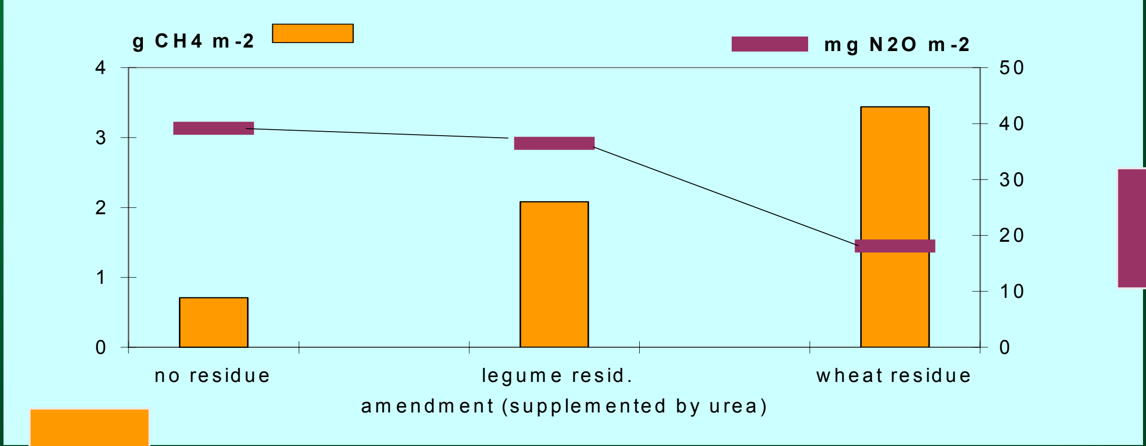
Global mitigation potential in agriculture



Strategies for reducing GHG emission from rice-wheat rotation

Generic strategy	GHG	Crop
1. Managing organic input	CH_4	Rice
2. Improving N fertilization	N_2O	Rice, wheat
3. Modifying irrigation patterns	CH_4	Rice
4. Improving crop cultivars	CH_4	Rice
5. Increasing soil organic-C	CO_2	Rice, wheat

CH_4/N_2O emissions from rainfed rice



CH_4:

GWP=21

N_2O:

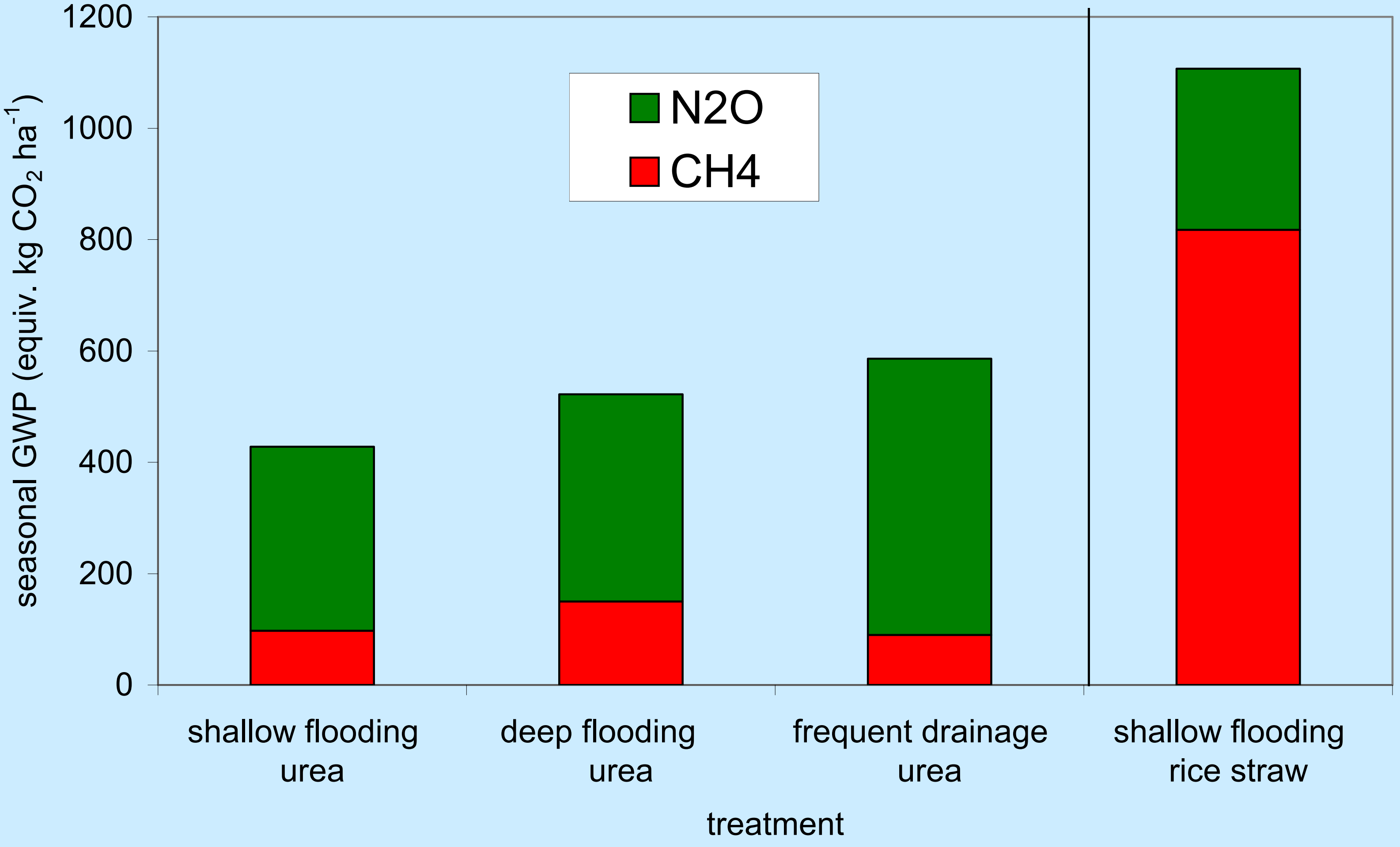
GWP

=310

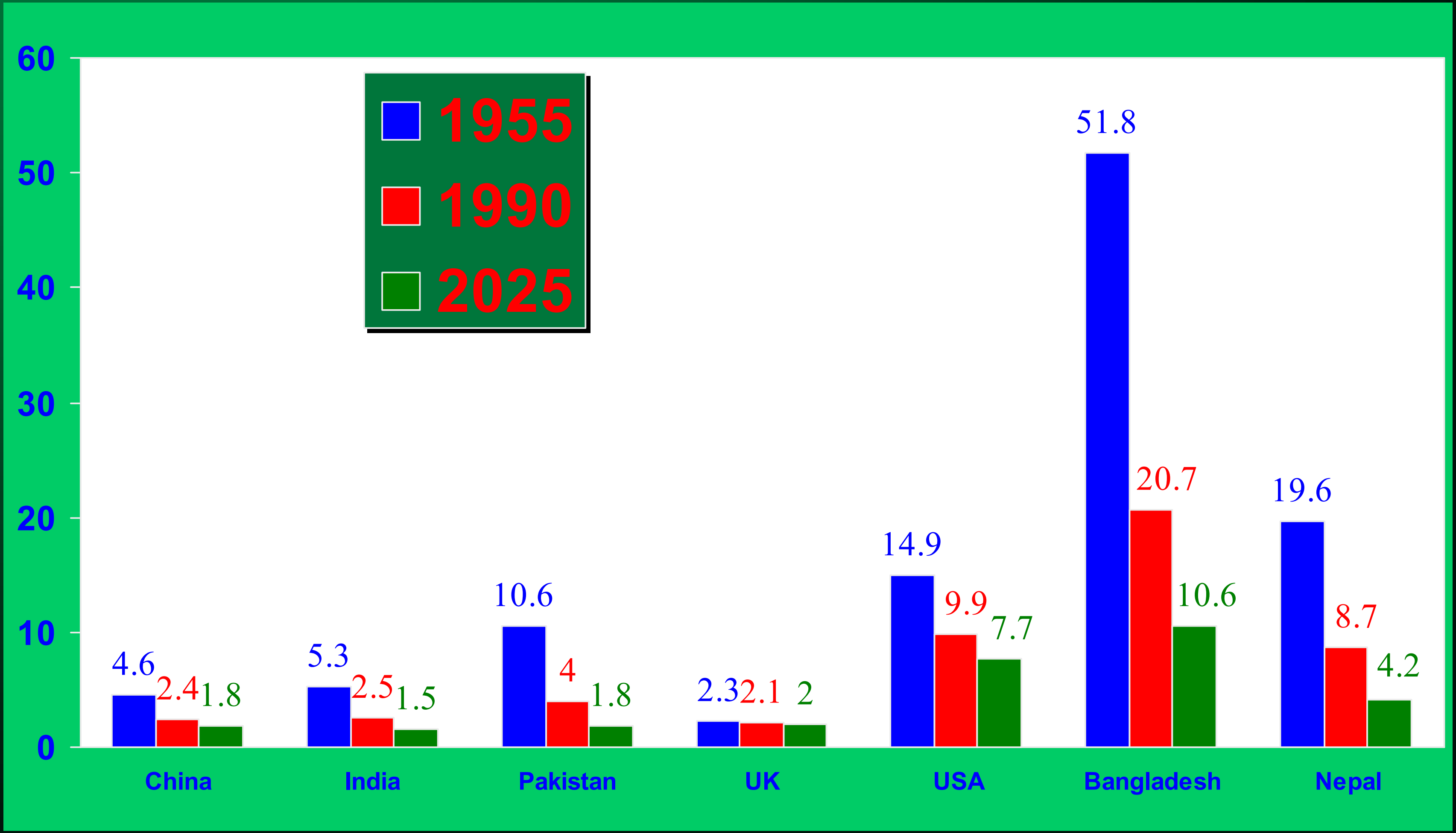
GLOBAL WARMING POTENTIAL

(GWP of CO_2 =1)

GWP of flooded rice fields



Per capita water availability in selected countries ('000 m^3)



Mitigating methane emission from rice

Puddled, transplanted, continuously submerged

More water

More labour

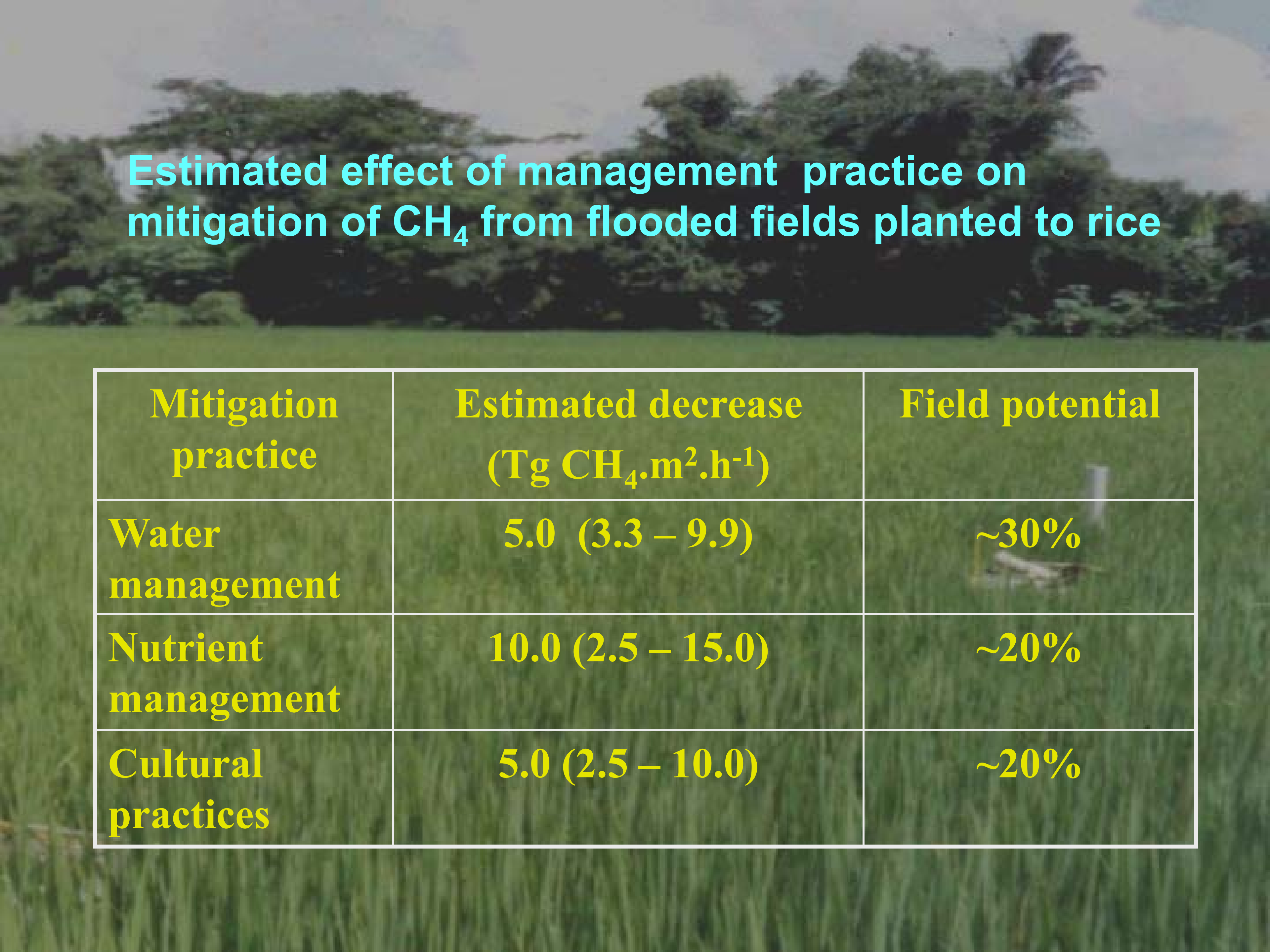
More methane

Aerobic rice

Direct seeded rice

SRI

Less water, Less methane



Estimated effect of management practice on mitigation of CH_4 from flooded fields planted to rice

Mitigation practice	Estimated decrease (Tg $CH_4.m^2.h^{-1}$)	Field potential
Water management	5.0 (3.3 – 9.9)	~30%
Nutrient management	10.0 (2.5 – 15.0)	~20%
Cultural practices	5.0 (2.5 – 10.0)	~20%

Impact of water regime on CH_4 emission from rice fields at CRRI, Cuttack

Rice Variety	Water regime	Mean emission ($mg.m^{-2}.d^{-1}$)	Seasonal flux ($kg.ha^{-1}$)	% Change
CR 749-20-2	Cont. fl	16.32 ± 27.61	18.61	-
	Int. fl.	13.80 ± 18.89	15.73	-15.48

Impact of cultivation practices on CH_4 emission from rice fields (Data from field experiments conducted at CRRI, Cuttack)

Cultivation practice	Rice variety	Treatment	Seasonal flux ($kg.ha^{-1}$)	Grain yield ($Mg.ha^{-1}$)	% Change
Stand establishment	Gayatri	Transpl.	30.22	5.4	-
		D.S.	24.36	4.2	- 19.4
Crop spacing	Ratna	Close spacing	28.34	2.7	-
		Wide spacing	26.22	2.8	- 7.5
Ratooning	IR-36	Main crop	11.22	3.8	-
		Ratoon	15.71	1.4	40.01
Crop sequence		Rice-rice	39.96	-	-
		Rice-upland crop	12.52	-	- 68.67

Selecting proper cultivar / cultivation practice

Methane emission from a rainfed alluvial field planed to different rice cultivars under uniform field conditions (CRRI, Cutack)

Rice cultivar	Seasonal flux (kg.ha^{-1})	Grain yield (Mg)	Kg CH_4 . Mg^{-1} grain	% Change
IR 72	25.84	2.37 ± 0.80	10.90	-
Gayatri	22.58	3.15 ± 1.05	7.16	-13
Tulasi	20.21	3.28 ± 1.45	6.16	-22
Lalat	44.41	3.85 ± 0.72	11.53	72

Effect of P and K applied through non-sulfate and sulfate-containing fertilizers on methane production at 30d in an alluvial soil of Cuttack

P-fertilizer source	Added P (mg.kg^{-1} soil)	Added K (mg.kg^{-1} soil)	Added S (mg.kg^{-1} soil)	Methane production (μg CH_4 kg^{-1} soil)
Control	0	0	0	4689b
SSP	100	0	175	5d
K_2HPO_4	100	426	0	4942a
K_2HPO_4 + K_2SO_4	100	678	175	29d

Soil Biol Biochem 30: 177-181, 1997)

Seasonal CH_4 emission from flooded paddy following application of potassium

Treatments	Mean flux (kg.ha^{-1})	% change	Grain yield (Mg.ha^{-1})
1. Control (K_0)	125.34	-	4.95
2. + K_{30}	63.81	- 49.09	5.80
3. + K_{60}	82.03	- 34.60	5.72
4. + K_{120}	64.43	- 48.60	6.02

Biol. Fertil. Soils 42 : 532-541 (2006)

Azolla ferns in rice fields

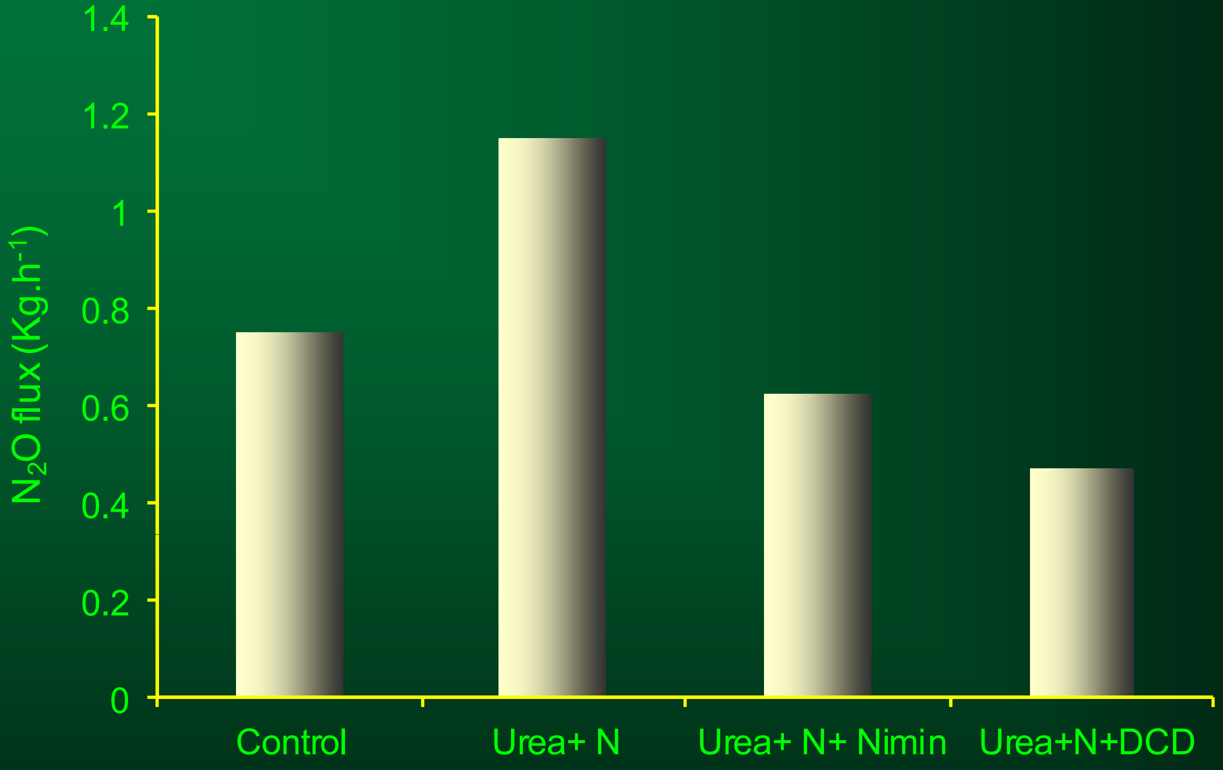
Methane efflux from flooded paddy following application of Urea and Azolla

Treatment	Grain yield (Mg. ha^{-1})	Cumulative CH_4 emission (kg. ha^{-1})	kg CH_4.Mg^{-1} grain yield
Control (No N)	3.58^{a}	94.94^{a}	26.52
Urea (60 kg N)	4.58^{b}	155.28^{c}	33.90
Azolla incorporated (30 kg N) + Urea (30 kg N)	4.38^{b}	149.37^{c}	34.10
Azolla dual cropping (30 kg N) + Urea (30 kg N)	4.33^{b}	89.29^{a}	20.62
Azolla incorporated (30 kg N)+ Azolla dual cropping (30 kg N)	4.24^{b}	105.64^{b}	24.92

Agriculture, Ecosystems and Environment 79 (2000) 73–83

Seasonal CH_4 emission from flooded paddy following application of nitrification inhibitor

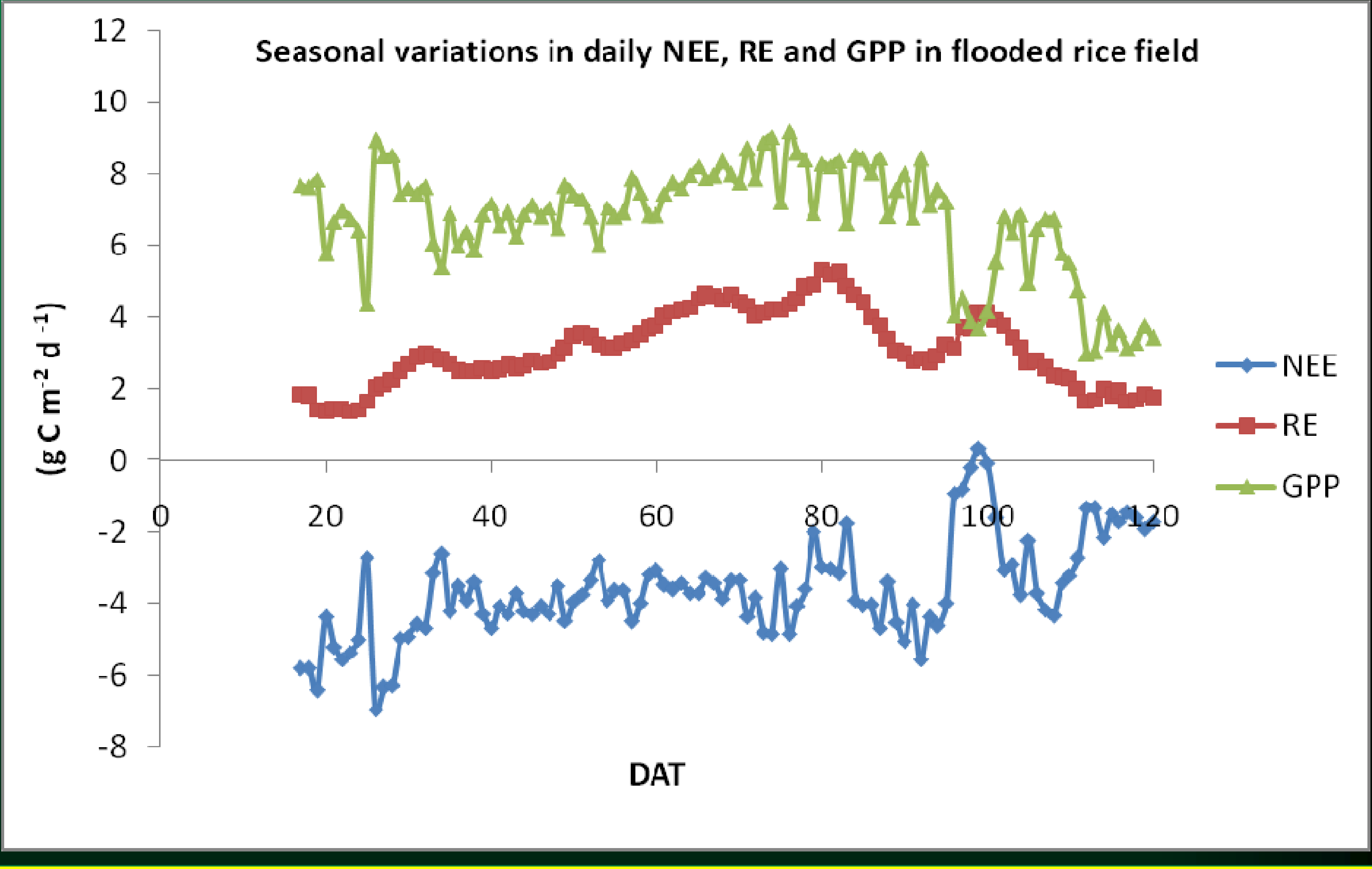
Treatments	Mean flux ($kg.ha^{-1}$)	% change
1. Urea-N	70.10	-
2. + Nimin	76.84	+ 9.61
3. + DCD	60.69	- 13.42



Effect of Nimin and DCD on cumulative N_2O emission from flooded rice field

Total C loss as CH_4 from a tropical Indian paddy during the 36 years of intensive rice-rice cropping

Treatments	Organic amendments (Mg ha^{-1})	C applied through organic amendments (Mg ha^{-1})	C applied through crop residues (Mg ha^{-1})	C left over in soil from organic amendments (Mg ha^{-1})	Loss and gains of C (Mg. ha^{-1})	C loss through CH_4 emission (Mg . $ha^{-1}y^{-1}$)	Cumulative C loss through CH_4 emission (Mg ha^{-1})	Contribution of CH_4 to the total C loss (%)	% left over C of the applied amount from	
									Organic amendments	Organic amendments + crop residues
Control	-	-	109.2	-	-2.3	0.045	1.63	1.46		
N	-	-	131.1	-	0.3	0.117	4.19	3.21		
NP	-	-	144.8	-	14.8	0.055	1.97	1.51		
NPK	-	-	151.0	-	17.0	0.104	3.75	2.79		
NPK + compost	180	8.75	164.4	6.96	27.5	0.179	6.44	4.71	79.6	31.5



Seasonal variation in daily GPP, RE and NEE in flooded field planted to rice during dry season, 2010.

Total C budget in flooded rice field from dry season 2010 (g C m^{-2})

Net ecosystem CO_2 exchange (NEE)	-377
Gross primary production (GPP)	705
Ecosystem respiration (Re)	327
Re / GPP	0.46

Flooded paddy serves as a net sink for CO_2

Economic and environmental viability analysis of different rice-based cropping systems under irrigated condition

Treatments	GWP* (Total CO2 equivalent kg.ha^{-1})	Production cost $(\$\ \text{ha}^{-1})$	Market cost $(\$\ \text{ha}^{-1})$	Net profit $(\$\ \text{ha}^{-1})$	C-credit compliance $(\$\ \text{ha}^{-1})$
Rice-rice	7.67	411.96	980.50	568.54	299.20
Rice + potato + sesame	2.18	687.09	1992.80	1305.71	85.02
Rice + maize + cowpea	1.70	829.17	1929.20	1100.03	66.30
Rice + sunflower + greengram	1.74	521.92	1166.00	638.08	67.86
Rice + chickpea + greengram	2.21	572.21	1081.20	508.69	86.19

Thank You…