Rice nitrous oxide: a new solvable problem

Dr. K. Kritee & Richie Ahuja

Environmental Defense Fund

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High nitrous oxide fluxes from rice indicate the need to manage water for both long- and short-term climate impacts

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Global rice cultivation is estimated to account for 2.5% of current anthropogenic warming because of emissions of methane (CH_4), a short-lived greenhouse gas. This estimate assumes a widespread prevalence of continuous flooding of most rice fields and hence does not include emissions of nitrous oxide (N_2O), a long-lived greenhouse gas. Based on the belief that minimizing CH_4 from rice cultivation is always climate beneficial, current mitigation policies promote increased use of intermittent flooding. However, results from five intermittently flooded rice farms across three agroecological regions in India indicate that N_2O emissions per hectare can be three times higher (33 kg-$N_2O \cdot ha^{-1} \cdot season^{-1}$) than the maximum previously reported. Correlations between N_2O emissions and management parameters suggest that N_2O emissions from rice across the Indian subcontinent might be 30–45 times higher under intensified use of intermittent flooding than under continuous flooding. Our data further indicate that comanagement of water with inorganic nitrogen and/or organic matter inputs can decrease climate impacts caused by greenhouse gas emissions up to 90% and nitrogen management might not be central to N_2O reduction. An understanding of climate benefits/drawbacks over time of different flooding regimes because of differ-

of the total CO_2e_{100y} even under intermittently flooded conditions (13–15). None of the major rice-producing countries, including the two leading rice producers, China and India (16, 17), officially report rice-N_2O or related emission factors in their national GHG inventories submitted to the United Nations (3). Crucially, most policy recommendations on rice management that include consideration of climate impacts focus on reducing rice-CH_4 by alternate wetting and drying (AWD), also called intermittent flooding. Water levels during intermittent flooding are typically allowed to fall to 15 cm below the soil surface before another round of irrigation (13–15). The only notable global policy guidance document to recognize rice-N_2O is a recent modeling-based report (18), which suggested that, globally, neglecting contribution of soil carbon, rice-N_2O contributes 25% to the GHG impact of rice cultivation on a CO_2e_{100y} basis (9).

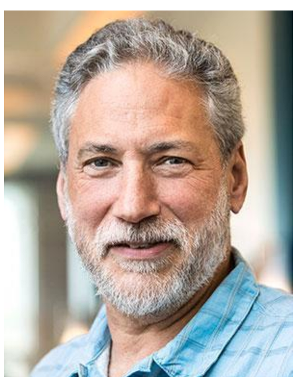
Many factors including redox, bioavailable N, and organic C affect the extent of N_2O formation that occurs primarily due to microbial nitrification–denitrification. Most research done to capture rice-N_2O to date has been performed at farms with

Significance

AGRICULTURAL SCIENCES

SUSTAINABILITY SCIENCE

Our team



Our partnerships: Fair Climate Network

Data from universities/government labs unreliable, inconsistent or scarce

the timbaktu collective in celebration of life

SEDS towards a greener tomorrow

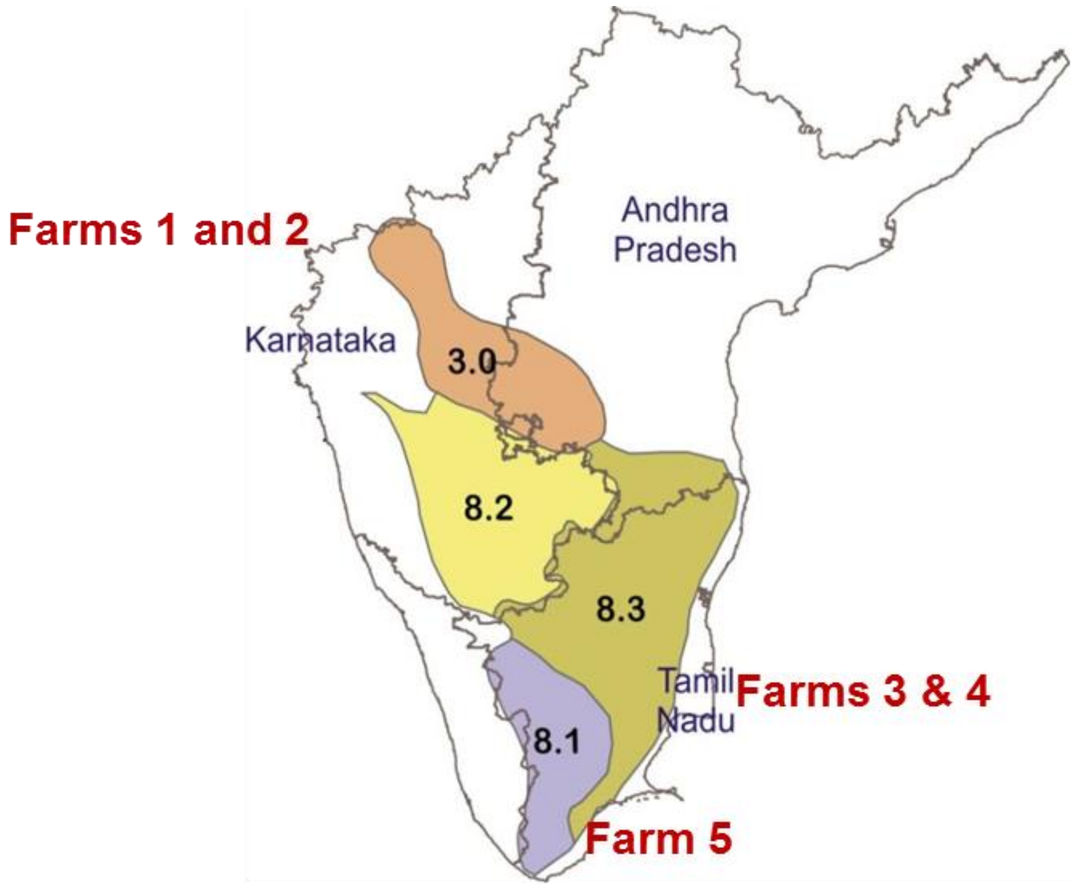
"SACRED" TRUST

Accion Fraterna ecology centre sustainable . human . nature

PWDS Palmyrah Workers Development Society

When we started, we bought into the current paradigm

Irrigated farms → Continuous flooding → Methane + small N_2O



Treatments at farmer-managed farms (2012-14)

1. Baseline → High fertilizer → → Surveys
2. Alternative → Low N + higher OM + Water(?) → → Local stakeholders

Published methodology

CARBON MANAGEMENT, 2015
http://dx.doi.org/10.1080/17583004.2015.1082233

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Sampling guidelines and analytical optimization for direct greenhouse gas emissions from tropical rice and upland cropping systems

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ABSTRACT
We describe a modified manual closed-chamber approach with detachable lid and ve
stackable chambers for sampling followed by simultaneous analysis of nitrous oxide
and methane (CH_4) for measuring greenhouse gas flux from rice and upland cropping s
in peninsular India. A meta-analysis of leading internationally/regionally recomm
approaches to monitor agricultural GHG emissions is presented to put our sampling

Groundnut cultivation in semi-arid peninsular India for yield scaled nitrous oxide emission reduction

K. Kritee, Drishya Nair, Rakesh Tiwari, Joseph Rudek, Richie Ahuja, Tapan Adhya, Terrance Loecke, Steven Hamburg, Filip Tetaert, et al.

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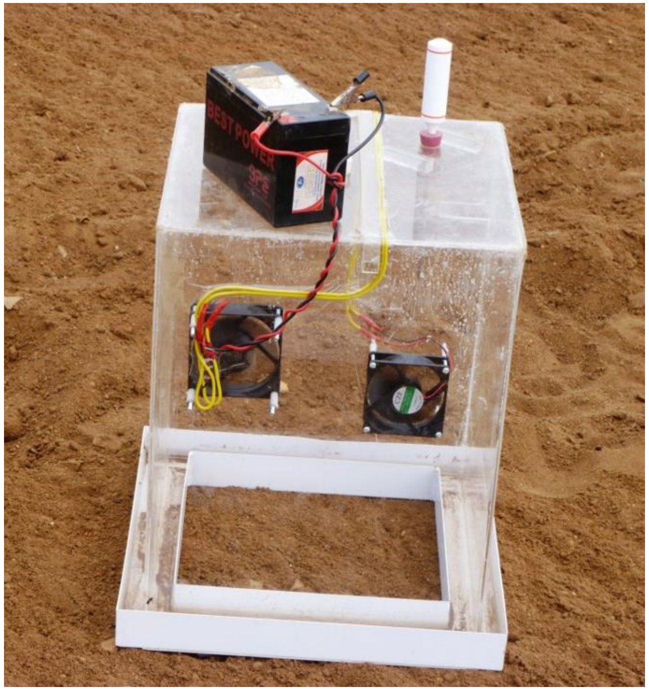
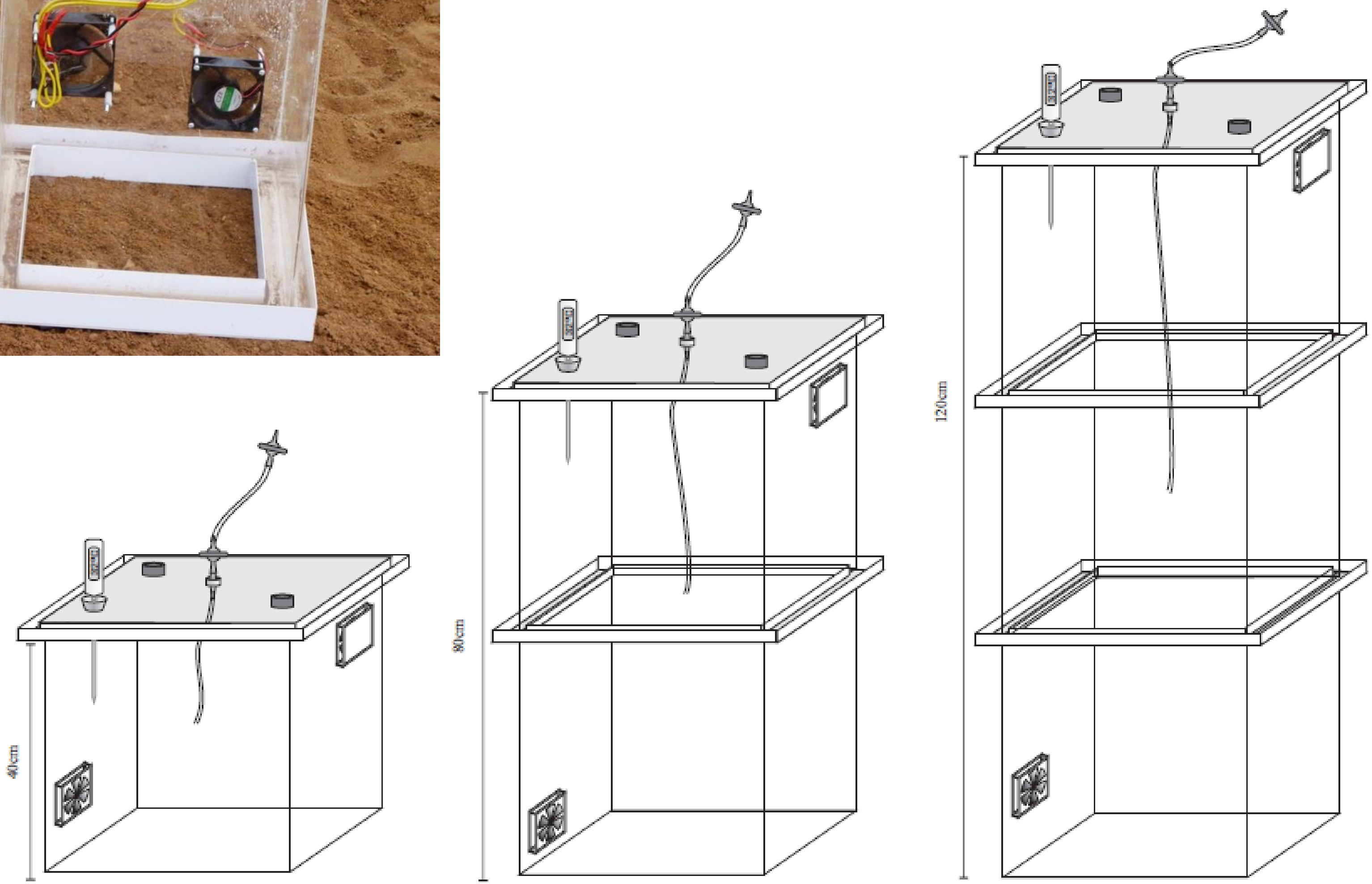


Stackable Manual chambers

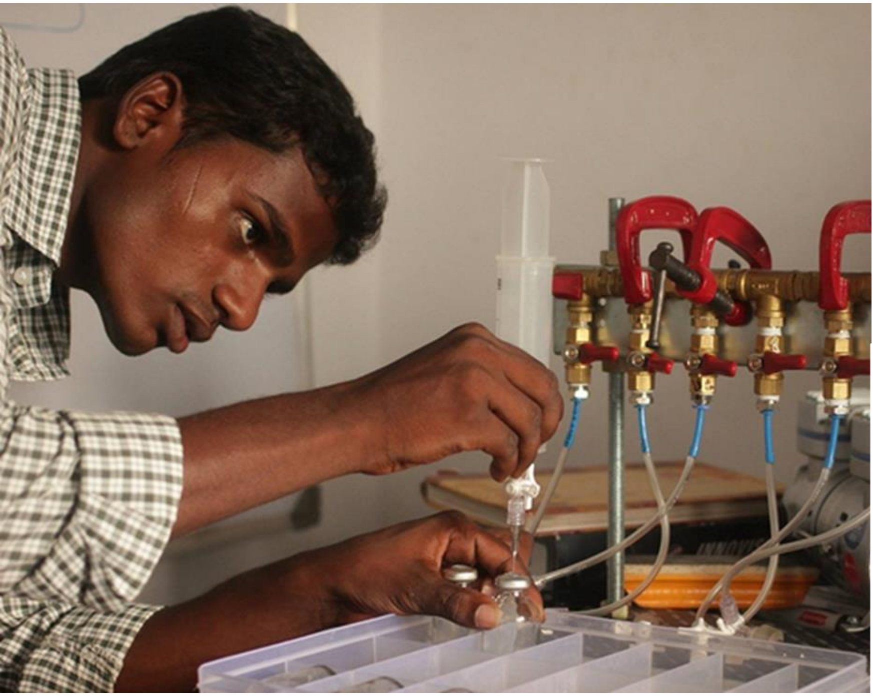


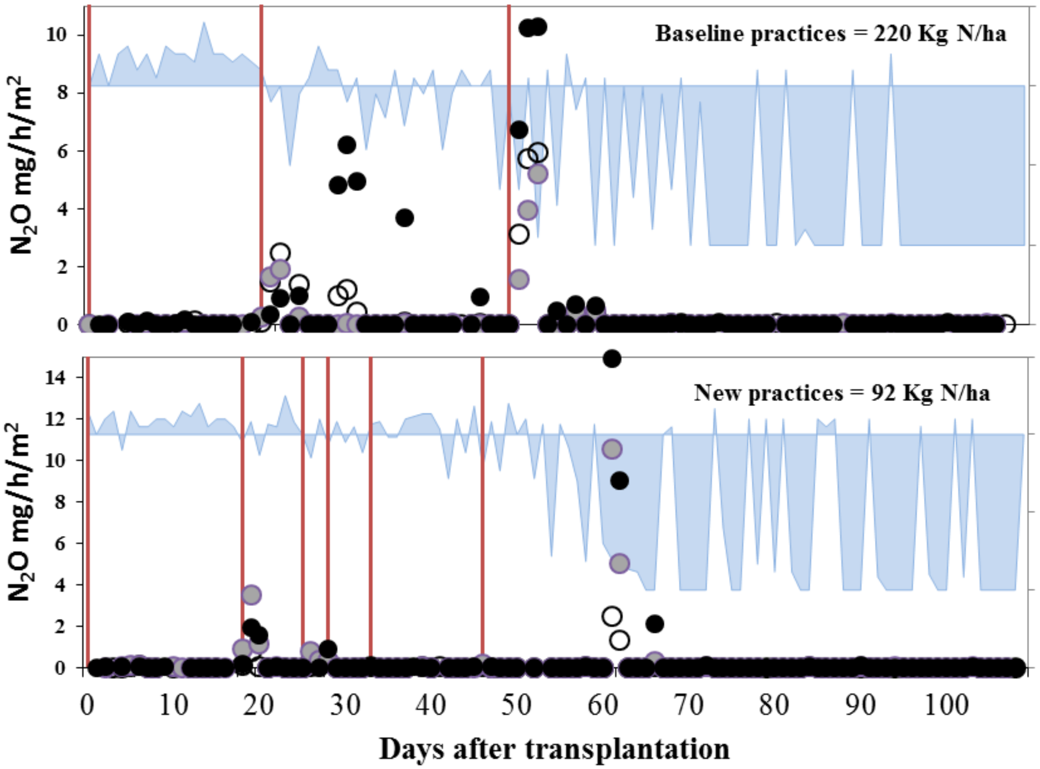
40cm
Sampling tube: 20cm

80cm
Sampling tube: 40cm

120cm
Sampling tube: 60cm

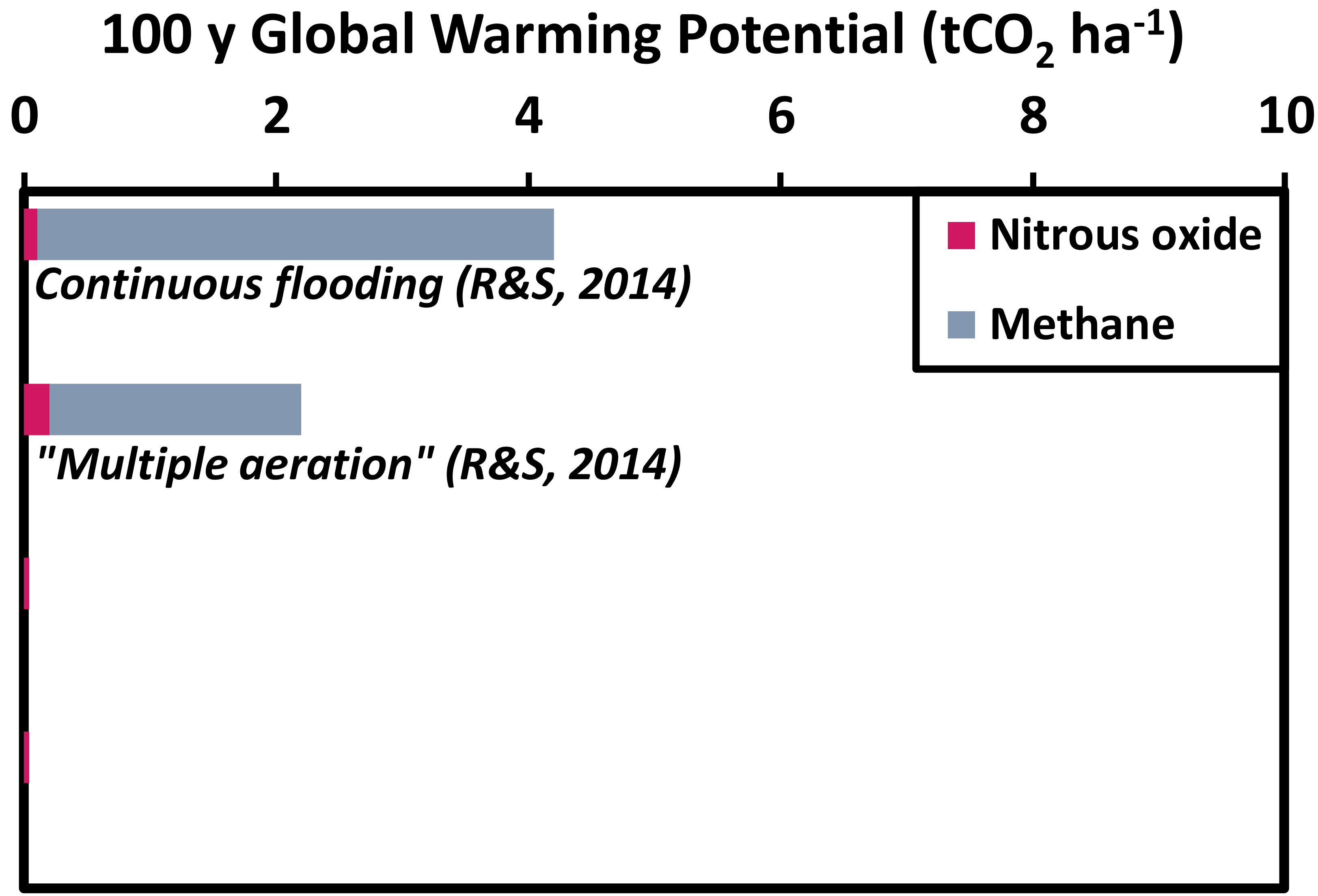
Best practices for tropical conditions



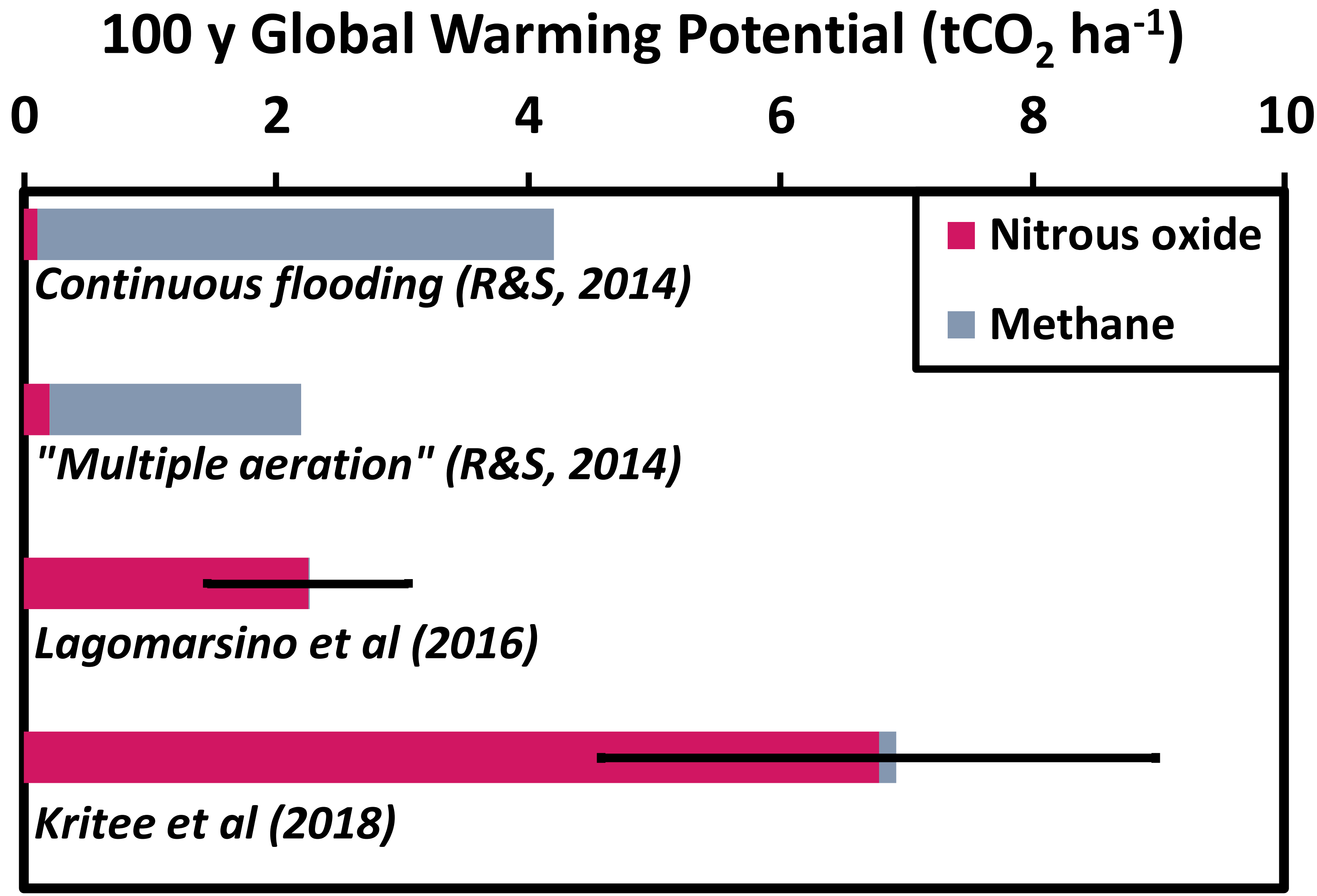


Rigorous sampling regime: All year

Comparison with climate smart practice brief (2014)

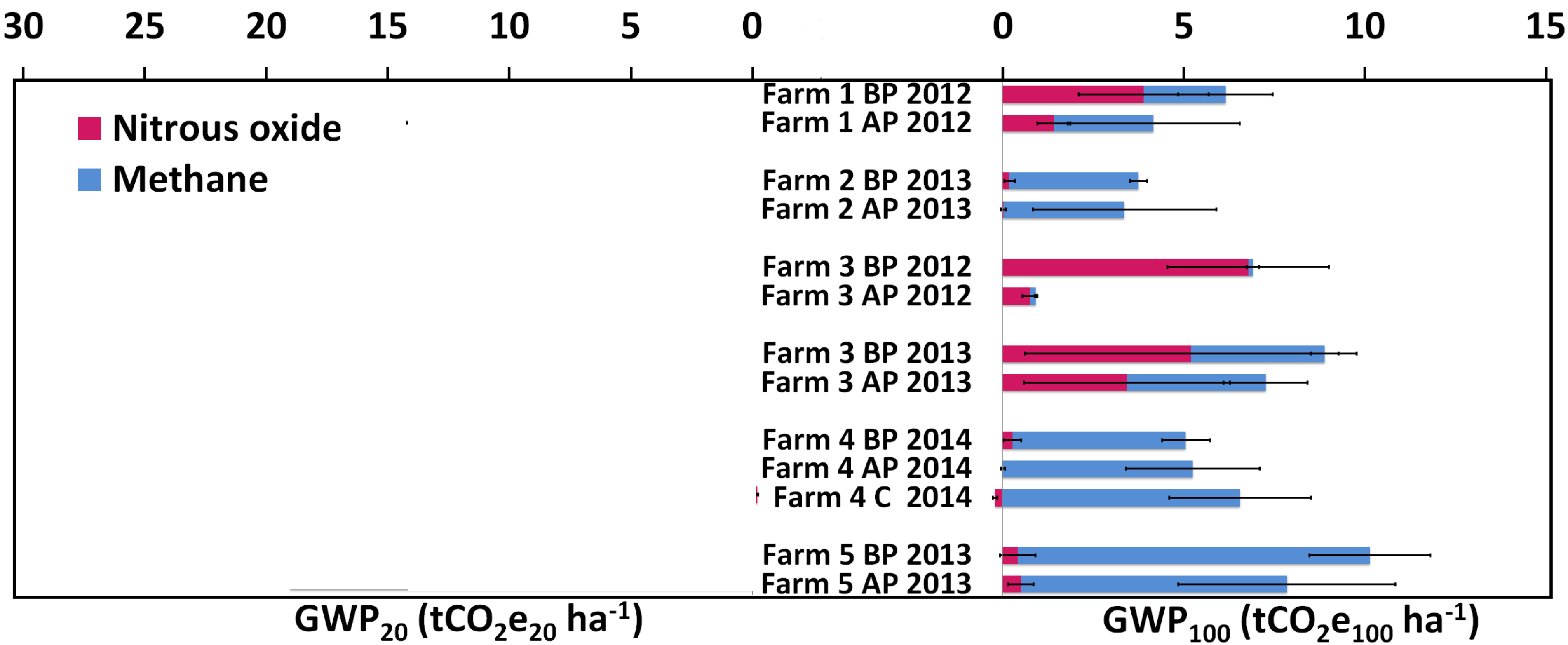


Comparison with climate smart practice brief (2014)

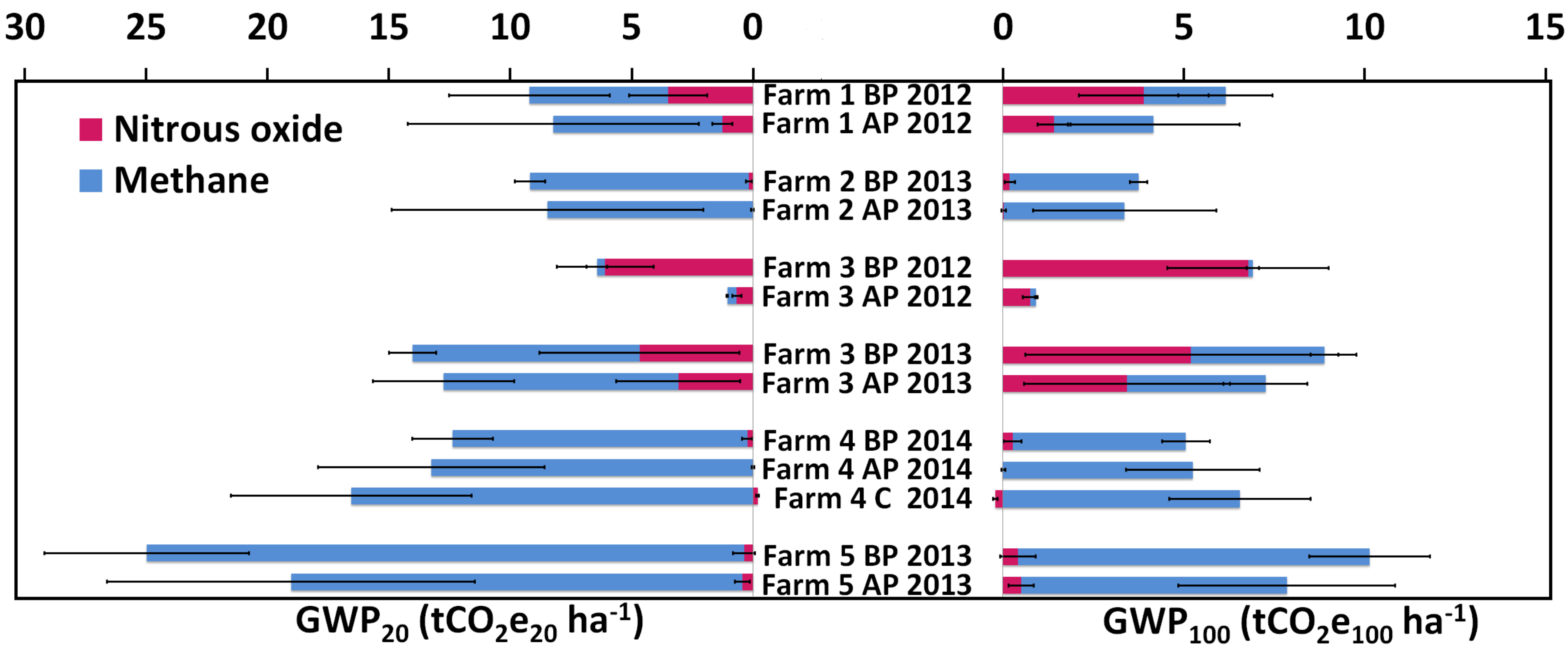


Very high #riceN_2O

10-20X typical AWD
Emission factor: Up to 50X continuous flooding
Mitigation potential = Up to 90% = 20X IPCC



Climate impacts (100 *vs* 20 years)



Experimental treatments: Details

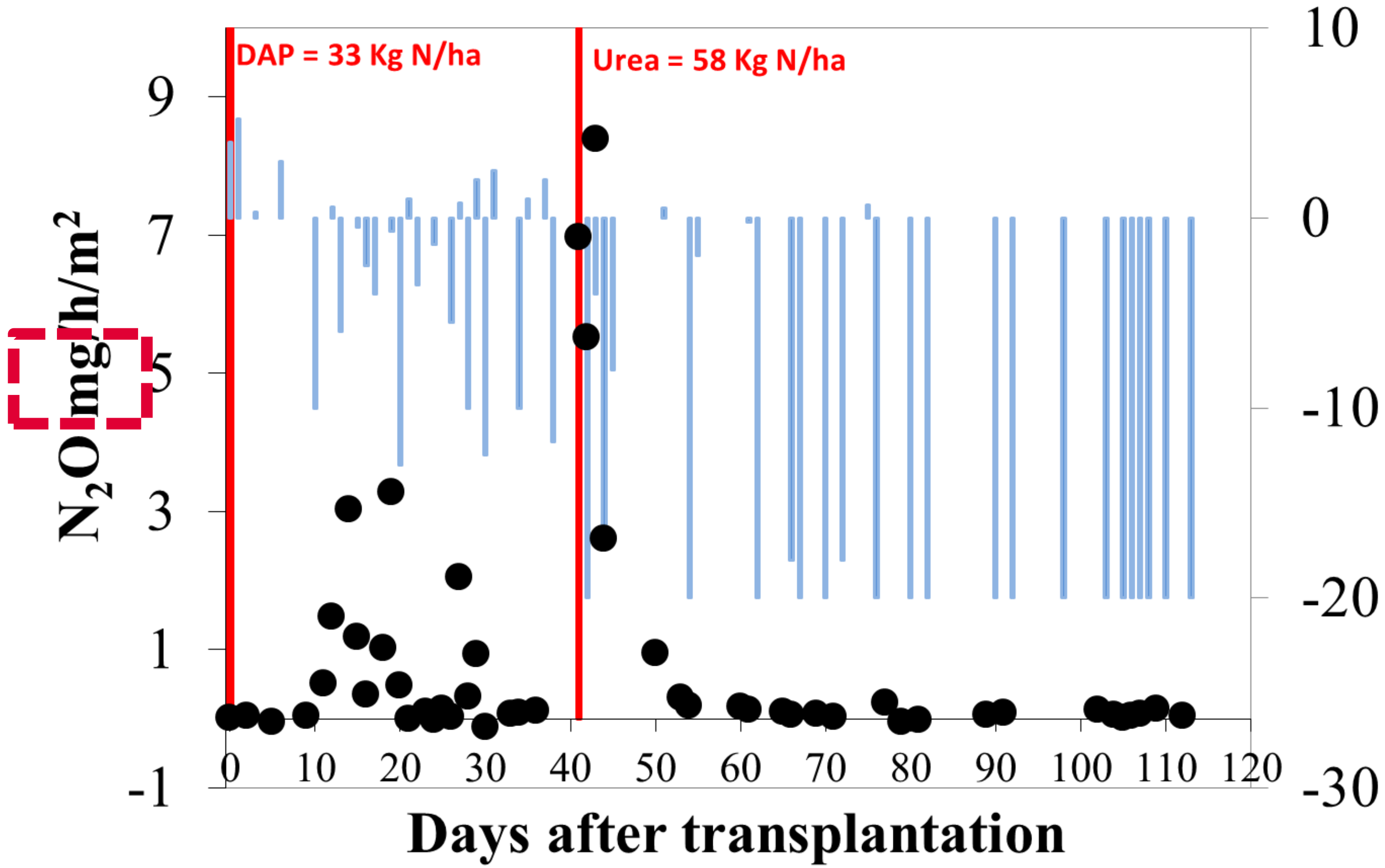
Table 1. Farm-specific baseline (business as usual), APs, and GHG emissions

Farm/year and treatment	Inorganic nitrogen,* kg·ha^{-1}	Carbon input,† t·ha^{-1}	Water index,‡ cm	Flood events§	Intermittent flooding regime¶	N_2O, kg·ha^{-1}	CH_4, kg·ha^{-1}
Agroecological region# 3.0 (seed variety BPT 5204)							
Farm 1 2012							
Baseline	91	3.9–4.5	−555 (85)	1	Medium	13.1 (6.03)	66.5 (38.4)
Alternate	0	4.1–4.8	−580 (144)	1	Medium	4.7 (1.53)	81.1 (69.7)
Farm 2 2013							
Baseline	243	5.6–6.8	−0.7 (33)	3	Mild	0.62 (0.47)	105 (7.23)
Alternate	0	8.4–10.0	−152 (16)	3	Mild	0.10 (0.20)	98.3 (74.5)
Agroecological Region# 8.3 (seed variety ADT 39)							
Farm 3 2012‖							
Baseline	219	0.0–0.0	−486 (10)	0	Medium	22.7 (7.47)	3.98 (4.89)
Alternate	61	2.7–3.7	−416 (81)	0	Medium	2.51 (0.69)	4.6 (0.39)
Farm 3 2013							
Baseline	202	0.6–0.8	−1,036 (16)	3	Intense	17.4 (15.4)	108 (11.2)
Alternate	20	2.5–3.0	−858 (52)	3	Intense	11.5 (9.55)	112 (33.9)
Farm 4 2014							
Baseline	174	1.0–1.2	−212 (63)	3	Mild/medium	0.88 (0.83)	141 (19.3)
Alternate	91	1.1–1.4	−316 (147)	5	Mild/medium	0.02 (0.2)	154 (54.3)
Agroecological Region# 8.1 (seed variety ASD 16)							
Farm 5 2013							
Baseline	121	0.0–0.0	15 (65)	3	Mild	1.39 (1.66)	286 (49.1)
Alternate	99	0.01–0.02	−155 (91)	4	Mild	2.47 (1.16)	216 (88.1)

Why did we observe high rice N_2O emissions?

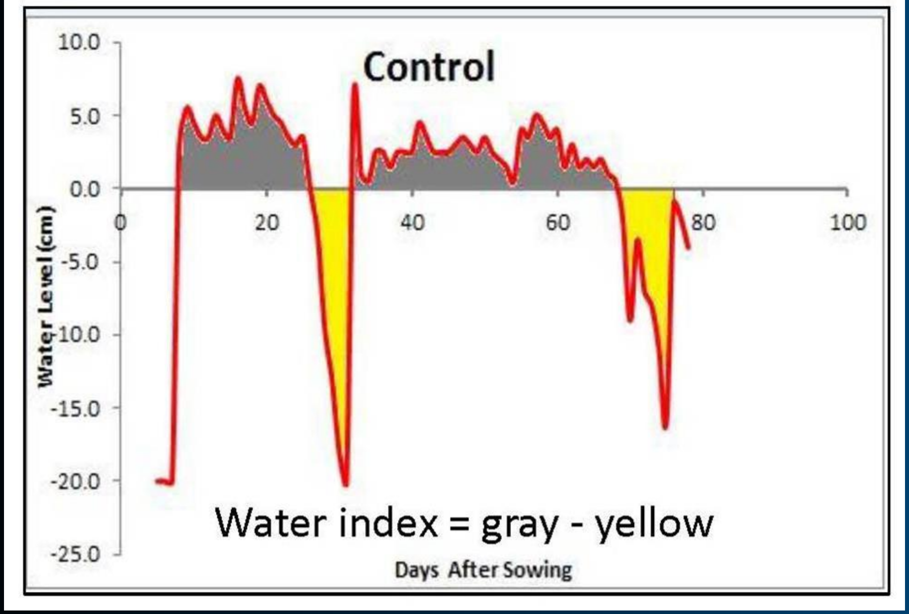
Hypothesis: Sampling intensity + Flood regimes

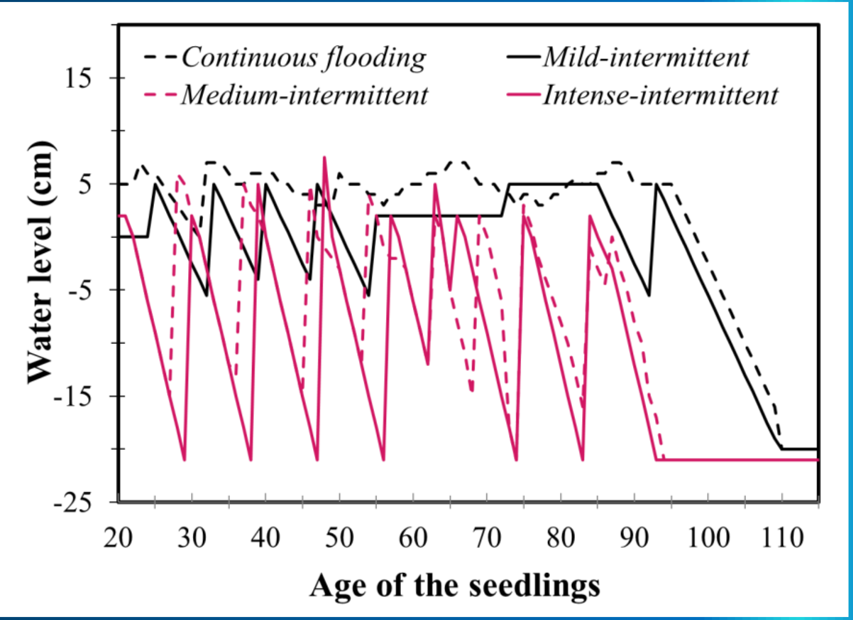
Spike 10-28 days after fertilizer addition



Hypothesis: Sampling intensity + Flood regimes

Flood events (> 3 days) Water index (cm)	0	1	2	3	4	5	6	7	8	>8
less than -1200		Upland								
-600 to -1200		Intense-intermittent flooding								
-250 to -600			Medium-intermittent flooding							
250 to -250					Mild-intermittent Flooding					
600 to 250							Continous flooding			
more than 600						Wetland/Deepwater				





Multiple regression models

**Multivariate regression analysis with 25 measured parameters*

Rice N_2O =

- \- *Extent of flooding*
- \- *Flooding frequency*
- \+ *Nitrogen fertilizer*
- \- *Organic matter*

Rice CH_4 =

- \+ *Flooding frequency*
- \+ *Soil organic matter*
- \+ *Organic matter*

$$N_2O = -0.01*(\text{water index}) - 0.91*(\text{flood events}_{>3\ \text{days}}) + 0.02*N_{inorganic} + \epsilon 1$$

$$CH_4 = 34*(\text{flood events}_{>3\ \text{days}}) + 88*SOM + \epsilon 2$$

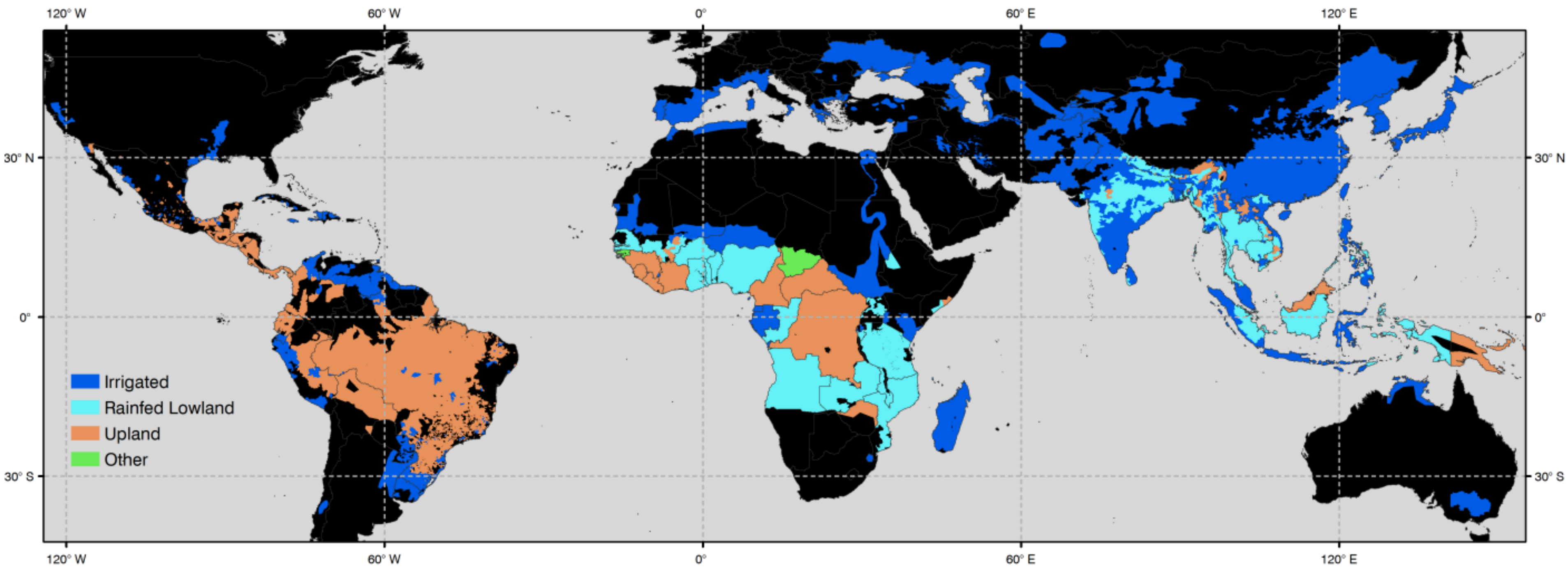
EDF White paper

How big could the #riceN_2O elephant be?
Are there any potential hotspots?

Limited global geospatial rice-N_2O risk analysis

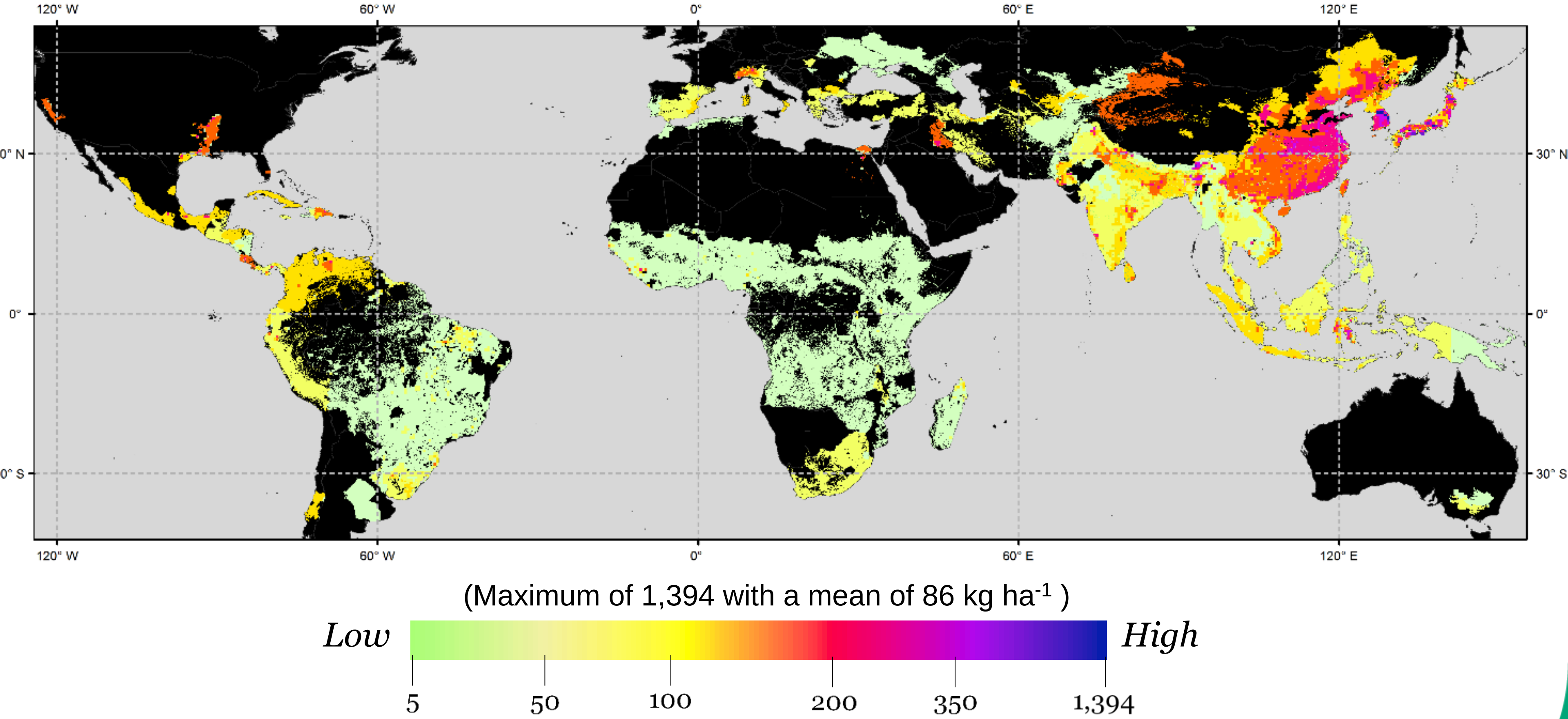
Rice management classes in the world: Dominant system

(IRRI, 2011)



Global rice inorganic N fertilizer use in 2000

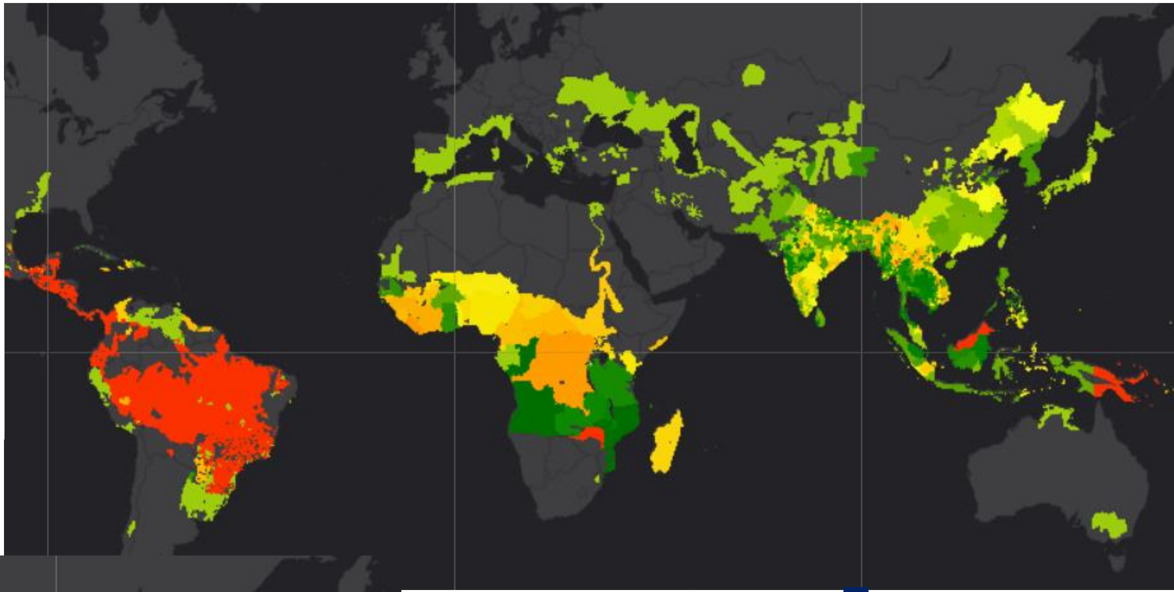
(Mueller 2012)



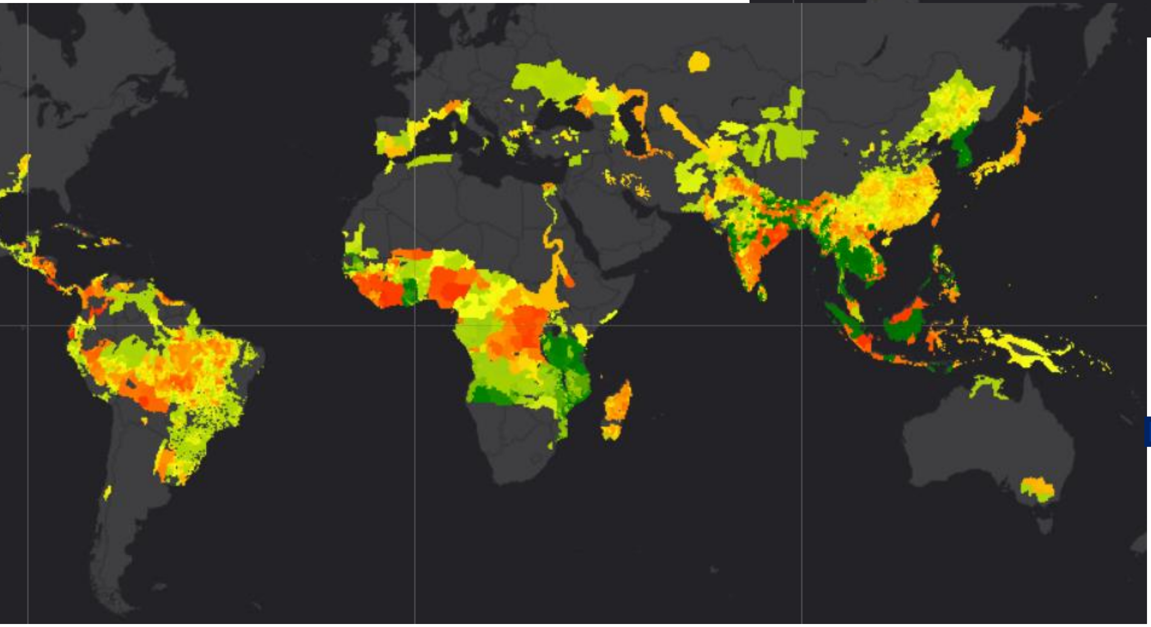
Medium-intermittent vs continuous flooding

Interactive maps,
blogs & global analysis

edf.org/riceN2O



Rice N_2O risk per hectare



Total N_2O risk
per IRRI defined region

Qualitative assessment: Risk of elevated N_2O emissions

Low — High

Potential change in climate impacts of rice

- Global Rice CH_4 = 700-1250 MMT CO_2e_{100} *(EPA-MAC 2013, IPCC 2013)*
  = 10-12% anthropogenic or 15-20% Ag CH_4

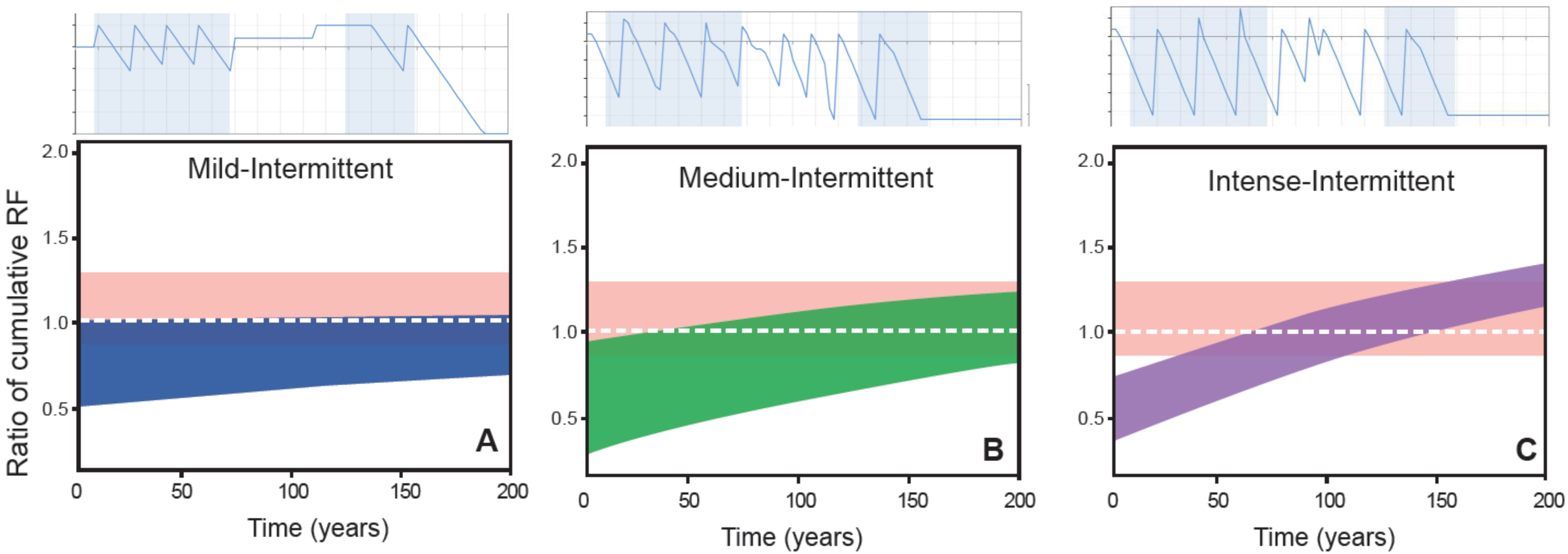
New: 1500-2000

- Global rice mitigation potential
  - 230 MMT CO_2e_{100} (IPCC 2007)

New: 450-550

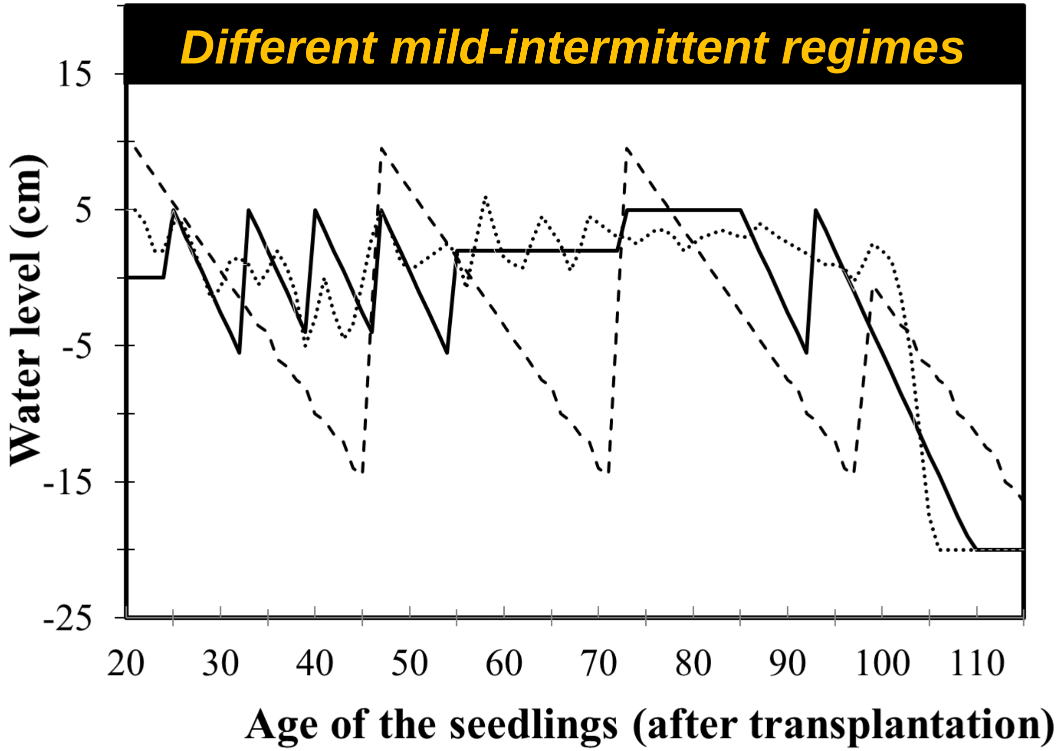
Climate impact over time: Four flooding scenarios

Current recommendations could give us short-term win, long-term loss



Potential pathways for reducing both CH_4 & N_2O

We suggest mild-intermittent flooding which has of water index between 250 to -250 cm



Summary of change in understanding of climate impacts of rice cultivation

	Previous literature	After Kritee et al (2018) & this report
Empirical data		
Maximum hourly flux (µg N_2O m^{-2} h^{-1})	2,100	15,000
Maximum seasonal flux (kg ha^{-1} $season^{-1}$)	9.9	32.8
Emission factor (% of added N converted to N_2O)*	0.02 to 0.7%	0.02 to 31%
Maximum rice-N_2O Mitigation potential (tCO_2e_{100} ha^{-1})	0.3#	6
Global extrapolation		
Global rice-N_2O emissions (MMT N_20)	0.08-0.84**	1.5-2.4**
Global rice-N_2O (MMT tCO_2e_{100})	24-250**	447-715**
Global climate impact of rice cultivation (MMT tCO_2e_{100})	700-1250***	1500-1930###
Global mitigation potential (MMT tCO_2e_{100})	230	450-550##
General understanding		
Climate impacts of rice cultivaton	Short-term	Both short- and long-term
Greenhouse gases from rice fields reported to UNFCCC	CH_4	CH_4 and hopefully N_2O
Main recommended strategy to reduce rice GHG emissions	Reduce water & organic input (with a mention of N use efficieny to tackle N_2O)	Co-manage fertilizer & organic input region-specifically with central focus on water
Best water management strategy for irrigated farms	Alternate wetting and drying	Mild-intermittent or shallow flooding (without extended flooding/drainage)

Implications

- Farmer benefit will drive all mitigation and adaptation efforts.
- Water management: key driver of both CH_4 + N_2O.
- Institutional capacity has been built and course can be corrected, if needed.
- When multiple aeration is involved, N_2O can be important
  - Flooding regimes at farmer-managed irrigated/rainfed farms.
  - GHG sampling >50% of days season^{-1} for intense flood regimes.

Questions and comments?

edf.org/RiceN2O

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