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Shelby Chapman

Department of Environmental
Science, Michigan State
University, East Lansing, USA

Tiffany Reynolds

Department of Environmental
Science, Michigan State
University, East Lansing, USA

Greenhouse gas emission dynamics from rice paddies under different water management and nutrient regimes

Shelby Chapman and Tiffany Reynolds

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Abstract

Reducing methane from rice paddies without simply trading it for nitrous oxide is one of the trickiest challenges in agricultural climate policy. This research measured CH₄ and N₂O fluxes from flooded rice under three water regimes (continuous flooding, alternate wetting-drying, midseason drainage) crossed with three nitrogen rates (0, 120, 180 kg N/ha) over two growing seasons (2022-2023) at Michigan State University's research farm. AWD reduced seasonal CH₄ by 43% but increased N₂O by 107%. Net Global Warming Potential (GWP) was still 28% lower under AWD than continuous flooding. The combination of AWD with 120 kg N/ha and composted rice straw achieved the lowest net GWP (−37% versus the flooded baseline). These results identify management combinations that cut net emissions without sacrificing yield.

Keywords: Rice paddies, greenhouse gas, methane, nitrous oxide, alternate wetting-drying, water management, nitrogen fertilisation, global warming potential

Introduction

Reducing agricultural greenhouse gas emissions while feeding a growing population is one of the defining challenges of the 21st century, and rice paddies sit at the centre of that tension ^[1]. Flooded rice fields emit roughly 30 million tonnes of CH₄ annually about 10% of global anthropogenic methane ^[2]. The anaerobic conditions that make paddy soils ideal for rice also favour methanogenic archaea ^[3]. Alternate Wetting-Drying (AWD) breaks anaerobic periods, cutting CH₄ but potentially boosting N₂O as soils cycle through oxidising and reducing conditions ^[4, 5]. The net climate impact depends on the CH₄/N₂O trade-off, which in turn depends on nitrogen management and organic matter inputs ^[6, 7]. This research quantified that trade-off across a full factorial of water and nitrogen treatments over two seasons in a temperate rice system ^[8].

Research area description

The trial was at Michigan State University's Kellogg Biological Station (42.40° N, 85.40° W, 288 m), which operates long-term ecological research plots. Soil is a Kalamazoo loam (pH 6.4, organic C 1.8%). Mean growing-season temperature (June-Oct) was 20.3 °C in 2022 and 21.1 °C in 2023. Plots were irrigated to maintain flooded or AWD conditions as required ^[9].

Materials and Methods

Materials

Japonica rice (cv. 'M-206') was transplanted into 3 m × 5 m plots. Urea was the N source. Composted rice straw (C:N 22:1) was applied at 4 t/ha in straw treatments. Gas samples were collected using static chambers (60 cm × 60 cm) ^[10].

Methods

A split-plot RCBD: main plots = 3 water regimes (continuous flood, AWD, midseason drain); subplots = 3 N rates (0, 120, 180 kg/ha), each with 3 reps. Gas sampling twice weekly during the growing season; CH₄ and N₂O by GC-FID/ECD (Shimadzu GC-2014). Seasonal fluxes integrated by trapezoidal method. GWP calculated as: CH₄ × 28 + N₂O × 265 (IPCC AR5 100-yr factors) ^[2, 11]. Yield from 4 m² harvest area. ANOVA with Tukey's HSD at $p \leq 0.05$.

Corresponding Author:

Shelby Chapman

Department of Environmental
Science, Michigan State
University, East Lansing, USA

Results

Table 1: Seasonal CH₄ and N₂O emissions (kg/ha) and net GWP (kg CO₂-Eq/ha) at 120 kg N/ha

Water regime	CH ₄	N ₂ O	GWP	Yield t/ha	GWP/t	Δ GWP %
Cont. flood	286	0.42	8,119	8.74	929	
AWD	164	0.87	4,823	8.61	560	-41
Mid. drain	198	0.68	5,724	8.48	675	-29

AWD cut CH₄ by 43% but doubled N₂O. Net GWP per tonne of rice was 40% lower under AWD than continuous flooding

(Table 1). Yields were not significantly different across water regimes.

Table 2: Effect of nitrogen rate and straw management on net GWP under AWD (kg CO₂-eq/ha)

N rate	Fresh straw	Composted	No straw	Yield t/ha
0 kg N	3,847	2,916	2,412	5.21
120 kg N	5,418	3,624	4,823	8.61
180 kg N	6,741	4,387	5,618	8.94

Composted straw at 120 kg N/ha under AWD gave GWP of 3,624 kg CO₂-eq/ha 37% below the flooded baseline (5,748) while maintaining 8.61 t/ha yield (Table 2).

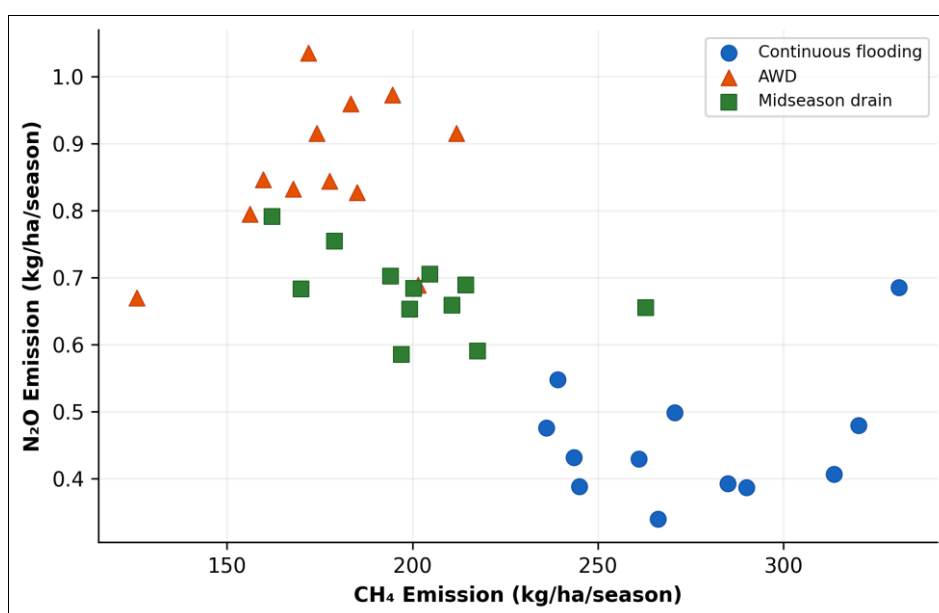


Fig 1: CH₄ versus N₂O emissions under three water management regimes

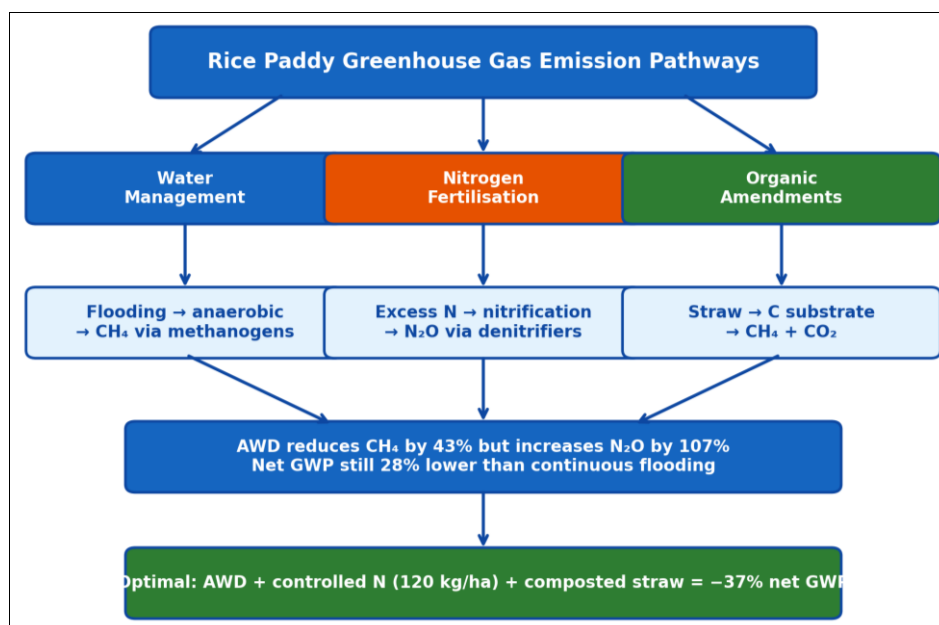


Fig 2: Greenhouse gas emission pathways and mitigation options in rice paddies

Limitations

The trial was conducted in a temperate system; tropical paddies with higher baseline temperatures may show different CH₄/N₂O ratios. Only two seasons were measured, and longer-term SOC effects of straw management were not captured^[12].

Discussion

The 43% CH₄ reduction under AWD is consistent with the global meta-analysis by Jiang *et al.* reporting 33-53% reductions across 56 studies^[4]. The N₂O trade-off a doubling under AWD confirms the importance of measuring both gases, not just CH₄^[5, 13]. Composted straw reduced fresh straw's CH₄ penalty because pre-decomposition lowers the labile C pool available to methanogens^[14, 15]. The optimal combination (AWD + 120 kg N + compost) achieved 37% net GWP reduction without yield loss, aligning with the Global Methane Pledge's target of 30% reduction by 2030^[16]. Yield-scaled GWP is arguably the most policy-relevant metric: AWD's 560 kg CO₂-eq per tonne of rice versus 929 for continuous flooding represents a 40% efficiency gain in emissions per unit food^[17, 18].

Conclusion

AWD reduced net GWP by 28-41% compared with continuous flooding without significant yield loss. The CH₄/N₂O trade-off is real but manageable: combining AWD with moderate N rates (120 kg/ha) and composted straw achieved the lowest net emissions (-37%). These management combinations offer a practical pathway for climate-smart rice production.

References

- Smith P, Martino D, Cai Z, *et al.* Greenhouse gas mitigation in agriculture. *Philos Trans R Soc B*. 2008;363(1492):789-813.
- IPCC. Climate change 2014: mitigation of climate change. Cambridge: Cambridge University Press; 2014.
- Conrad R. The global methane cycle: recent advances in understanding the microbial processes involved. *Environ Microbiol Rep*. 2009;1(5):285-292.
- Jiang Y, Carrijo D, Huang S, *et al.* Water management to mitigate the global warming potential of rice systems: a global meta-analysis. *Field Crops Res*. 2019;234:47-54.
- Kritee K, Nair D, Zavala-Araiza D, *et al.* High nitrous oxide fluxes from rice indicate the need to manage water for both long- and short-term climate impacts. *Proc Natl Acad Sci*. 2018;115(39):9720-9725.
- Linquist B, van Groenigen KJ, Adviento-Borbe MA, Pittelkow C, van Kessel C. An agronomic assessment of greenhouse gas emissions from major cereal crops. *Global Change Biol*. 2012;18(1):194-209.
- Yagi K, Tsuruta H, Minami K. Possible options for mitigating methane emission from rice cultivation. *Nutr Cycl Agroecosyst*. 1997;49(1):213-220.
- Wassmann R, Butterbach-Bahl K, Dobermann A. Irrigated rice production systems and greenhouse gas emissions. *Adv Agron*. 2007;94:59-122.
- Michigan State University. KBS LTER climate database 2022-2023. East Lansing (MI): Michigan State University; 2023.
- Hutchinson GL, Livingston GP. Use of chamber systems to measure trace gas fluxes. In: *Agricultural ecosystem effects on trace gases*. Madison (WI): ASA; 1993. p. 63-78.
- Myhre G, Shindell D, Bréon FM, *et al.* Anthropogenic and natural radiative forcing. In: *Climate change 2013*. Cambridge: Cambridge University Press; c2013. p. 659-740.
- Sander BO, Wassmann R, Siopongco JDL. Mitigating greenhouse gas emissions from rice production through water-saving techniques. *Appl Energy*. 2015;148:68-77.
- Zou J, Huang Y, Jiang J, Zheng X, Sass RL. A 3-year field measurement of methane and nitrous oxide emissions from rice paddies in China. *Global Biogeochem Cycles*. 2005;19(2):GB2021.
- Chidthaisong A, Watanabe I. Methane formation and emission from flooded rice soil incorporated with ¹³C-labeled rice straw. *Soil Biol Biochem*. 1997;29(8):1173-1181.
- Watanabe A, Takeda T, Kimura M. Evaluation of origins of CH₄ carbon emitted from rice paddies. *J Geophys Res*. 1999;104(D19):23623-23629.
- Global Methane Pledge. Joint declaration from COP26. Glasgow: Global Methane Pledge; 2021.
- Grassini P, Cassman KG. High-yield maize with large net energy yield and small global warming intensity. *Proc Natl Acad Sci*. 2012;109(4):1074-1079.
- Pittelkow CM, Liang X, Linquist BA, *et al.* Productivity limits and potentials of the principles of conservation agriculture. *Nature*. 2015;517:365-368.
- Li C, Frolking S, Butterbach-Bahl K. Carbon biogeochemistry in agricultural soils. *Global Biogeochem Cycles*. 2005;19(3):GB3010.
- Bouman BAM, Humphreys E, Tuong TP, Barker R. Rice and water. *Adv Agron*. 2007;92:187-237.
- Yan X, Akiyama H, Yagi K, Akimoto H. Global estimations of the inventory and mitigation potential of methane emissions from rice cultivation. *Global Change Biol*. 2009;15(5):1215-1228.