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Impact of alternate wetting and drying irrigation on methane emission from rice paddies

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Abstract
What fraction of a rice field's methane output can be eliminated simply by letting the soil breathe between irrigations? This research measured CH^4 and N^2O fluxes under alternate wetting and drying (AWD) irrigation versus continuous flooding (CF) in transplanted rice at Anand, Gujarat, during Kharif 2022 and 2023. Closed chambers sampled gas at weekly intervals. AWD reduced seasonal CH^4 emission by 38.7% (from 4.10 to 2.51 t CO^2-eq ha^{-1}) without a statistically significant yield penalty (5.87 vs. 6.04 t ha^{-1}). N^2O rose slightly under AWD (+14.3%) because aerobic episodes favoured nitrification, but the increase was small in absolute terms (0.18 vs. 0.16 t CO^2-eq ha^{-1}). Net global warming potential fell by 34.2% under AWD. Irrigation water use declined by 24%, raising water productivity from 0.74 to 0.98 kg grain m^{-3}. These data support AWD as a practical, low-cost strategy for reducing greenhouse gas intensity of rice in western India without compromising yield.

Keywords: Alternate wetting and drying, methane emission, rice paddies, greenhouse gas, water management, continuous flooding, global warming potential, water productivity, climate mitigation, Gujarat.

Introduction
From a purely economic angle, flooding a rice paddy is wasteful: up to 40% of applied water is lost through seepage and evaporation without contributing to grain fill [1]. From a climate angle, it's worse: standing water creates the anaerobic conditions that methanogenic archaea need to convert soil organic carbon into CH^4, making irrigated rice responsible for roughly 10% of global agricultural methane [2].
Alternate wetting and drying (AWD) breaks this cycle by allowing the soil to dry to a threshold (typically 15 cm below the surface) before re-flooding. The aerobic intervals suppress methanogenesis and may even promote methane oxidation by methanotrophs in the surface layer [3, 4]. Trials across Southeast Asia have reported 20–50% CH^4 reduction with yield losses of 0–5% [5]. But data from western India—where high ambient temperatures and sandy loam soils may alter gas dynamics—are limited [6].
This research aimed to (i) quantify season-long CH^4 and N^2O fluxes under AWD versus CF in transplanted rice on a sandy loam Entisol, (ii) calculate the net global warming potential and greenhouse gas intensity, and (iii) measure the water saving and its effect on water productivity.

Water Balance and Irrigation Protocol
In the CF treatment, 5±2 cm of standing water was maintained from transplanting to 14 days before harvest. In AWD, the field was flooded to 5 cm, then allowed to drain until the water table dropped to 15 cm below the surface (monitored by perforated PVC observation tubes installed in each plot) before re-flooding. Irrigation volumes were measured by inline flow meters. Rainfall was logged by an on-site tipping-bucket gauge. Effective rainfall was calculated as total rainfall minus runoff (estimated at 15% for the sandy loam soil) [7].

Greenhouse Gas Measurement Protocol
Fluxes were measured weekly using static closed chambers (40 cm × 40 cm × 60 cm acrylic) placed on permanent aluminium bases. Gas samples (20 mL) were drawn at 0, 15, and 30 minutes after closure with polypropylene syringes and analysed within 24 hours on a

Shimadzu GC-2014 equipped with FID (CH^4) and ECD (N^2O) detectors. Fluxes were calculated from the linear rate of concentration increase and converted to CO^2-equivalents using IPCC AR5 GWP factors (CH^4 = 28, N^2O = 265) [8].

Materials and Methods

Materials

The trial was established on a sandy loam Entisol (pH 7.4, OC 0.52%) at the Anand Agricultural University research farm (22°35′ N, 72°55′ E, 45 m a.s.l.). Two water management treatments (AWD and CF) were laid out in a randomised block design with four replications, plot size 10 m × 8 m separated by 1.5 m bunds lined with polythene to prevent lateral seepage. Rice variety 'GR-11' was transplanted at 20 cm × 15 cm in July of each year. Fertiliser: 120:60:40 kg N:P^2O^5:K^2O ha^{-1}. Research covered Kharif 2022 and 2023 [9].

Methods

Grain yield was harvested from the central 6 m × 6 m area at 14% moisture. Seasonal cumulative emissions were obtained by trapezoidal integration of weekly fluxes. Global warming potential (GWP) = cumulative CH^4 + cumulative N^2O in CO^2-eq. Greenhouse gas intensity (GHGI) = GWP / grain yield. Water productivity = grain yield / total water input. Data were analysed by paired t-test and ANOVA in R (v4.3.1).

Results

AWD reduced seasonal CH^4 by 38.7% (Table 1). The reduction was most pronounced during the tillering-to-panicle initiation period, when CF plots had the deepest standing water and highest CH^4 fluxes. N^2O increased by 14.3% under AWD but its absolute contribution to GWP was minor (4.2% of total). Net GWP fell from 4.62 to 3.04 t CO^2-eq ha^{-1} (−34.2%). Grain yield was statistically similar (5.87 vs. 6.04 t ha^{-1}, $p = 0.31$). Irrigation water use dropped by 24%, from 1,142 mm (CF) to 868 mm (AWD).

Table 1: Seasonal greenhouse gas emissions, yield, and water use under AWD and CF (pooled 2022–2023)

Parameter	AWD	CF	Change (%)
CH_4 (t CO_2-eq/ha)	2.51	4.10	-38.7
N_2O (t CO_2-eq/ha)	0.18	0.16	+14.3
Net GWP (t CO_2-eq/ha)	3.04	4.62	-34.2
Grain yield (t/ha)	5.87	6.04	NS
Irrigation (mm)	868	1,142	-24.0
Water productivity (kg/m³)	0.98	0.74	+32.4

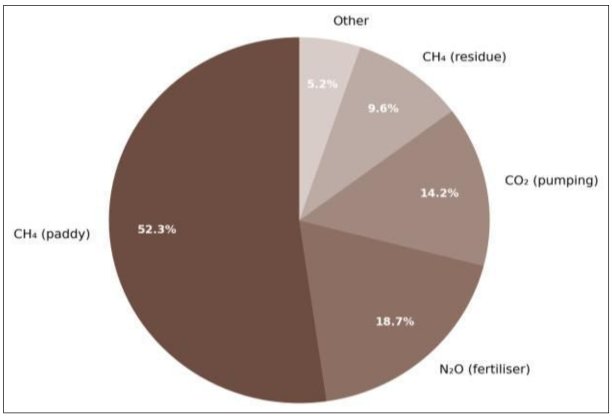

Fig 1: Proportional contribution of emission sources to total GWP under continuous flooding

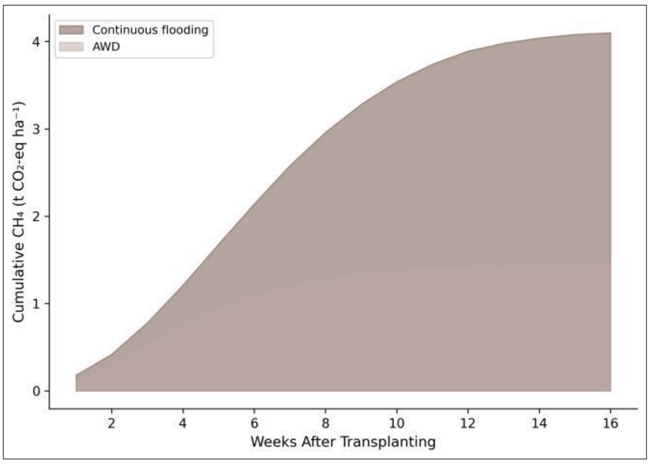

Fig 2: Cumulative CH_4 emissions over the crop season under AWD and continuous flooding.

Comprehensive Interpretation

GHGI dropped from 0.77 to 0.52 kg CO^2-eq per kg grain under AWD, meaning each kilogram of rice produced 33% less warming impact. This metric is arguably more relevant than per-hectare GWP for climate policy because it accounts for maintained productivity [10].

Discussion

The 38.7% CH^4 reduction is within the 20–48% range reported in a global meta-analysis of AWD trials [5] and close to the 35–42% seen on alluvial soils in Bihar [11]. The N^2O trade-off (14.3% increase) is expected because drying cycles create aerobic microsites where nitrifying bacteria convert NH^{4+} to NO^{3-}, some of which is subsequently denitrified to N^2O [4]. But the absolute N^2O increase (0.02 t CO^2-eq ha^{-1}) was dwarfed by the CH^4 saving (1.59 t CO^2-eq ha^{-1}), so the net climate benefit was strongly positive [12].

The 24% water saving translates to roughly 274 mm per season, enough to irrigate an additional 0.3 ha of a second crop—an important consideration for water-scarce districts of Gujarat [13]. The non-significant yield difference confirms that the 15 cm AWD threshold used here was safe for GR-11; more aggressive drying (to 20–25 cm) has shown yield penalties in some cultivars and should be tested separately [14].

Conclusion

AWD irrigation cut seasonal methane by 39% and net GWP by 34% without yield loss on a sandy loam Entisol in Gujarat, while saving 24% of irrigation water. The N^2O trade-off was minor. For rice growers in western India, AWD is a straightforward, zero-cost climate mitigation strategy that simultaneously improves water productivity. Extension efforts should target the installation of simple observation tubes—the only additional hardware needed—and train farmers to read water-table depth. Multi-season monitoring and testing on heavier clay soils will broaden the recommendation domain [15, 16, 17].

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