June 7-12, 2026
Nanjing, China
https://www.23wcss.org.cn/

• Alternate Irrigation Reduces Methane Emissions in Malaysian Rice Paddies

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ABSTRACT

Continuous flooding (CF) in Malaysian rice paddies under anaerobic soil conditions results in elevated methane (CH_4) emissions. Alternate wetting and drying (AWD) and mid-season drainage (MD) introduce periodic soil aeration, which can restructure soil microbial communities and modify methane (CH_4) fluxes. A tank experiment using Briah series *(Fine, mixed, isohyperthermic, Typic Endoaquepts)* soil planted with the MR297 rice variety was conducted to compare CF, AWD, and MD treatments arranged in a randomized complete block design. Methane fluxes were measured weekly using non-flow-through static chambers and gas chromatography, and interpolated weekly mean fluxes were used to estimate cumulative seasonal CH_4 emissions. Soil samples from the 0–15 cm layer were collected at 58 and 96 days after transplanting for 16S rRNA amplicon sequencing, and microbial community structure was assessed using Bray–Curtis principal coordinates analysis (PCoA), heatmaps of the 50 most abundant genera, and LEfSe biomarker analysis in MicrobiomeAnalyst. Seasonal cumulative methane emissions were 70.24, 30.75, and 15.93 g CH_4 m^{-2} under CF, AWD, and MD, respectively, corresponding to methane reductions of 56.21% under AWD and 77.32% under MD relative to CF. Plant height, leaf area, and grain yield did not differ significantly among irrigation treatments, indicating that AWD and MD imposed no yield penalty. PCoA revealed significant separation of microbial communities among treatments at both 58 and 96 days after transplanting (ANOSIM, $P = 0.001$), with CF communities clearly distinct from AWD and MD at 58 days, and AWD showing the most significant divergence at 96 days. Soils under CF were enriched in hydrogenotrophic methanogens, particularly Methanocella (Rice Cluster I) and Methanobacterium (Euryarchaeota), which coincided with higher methane emissions. In contrast, AWD and MD soils exhibited higher relative abundances of methanotrophic taxa such as Methylocystis (Alphaproteobacteria) and Pseudomonas (Gammaproteobacteria), consistent with enhanced methane oxidation and lower net CH_4 emissions. Alternate wetting and drying and mid-season drainage substantially reduced methane emissions from Malaysian paddy soil by approximately 77%, while maintaining rice physiological performance and yield. These mitigation effects are closely linked to a functional shift from methanogen-dominated microbial communities under continuous flooding to methanotroph-enriched assemblages under alternate irrigation regimes. Overall, the findings demonstrate that water management practices that steer soil microbial abundance and diversity provide a viable strategy for reducing paddy methane emissions without compromising productivity.

Acknowledgments

This study was funded by the Malaysian Ministry of Higher Education, the Fundamental Research Grant Scheme (Grant No.: FRGS/1/2019/STG03/UPM/02/8).