Global Methane Hub

Rice Methane Innovation Accelerator

STATE OF SCIENCE

Methane Formation and Emission from Rice Fields

Preapred by Achim Dobermann, September 2026

Unlike other crops, rice has the unique ability to grow and thrive in saturated, flooded soils, but this also results in emissions of CH_4 produced in the soil. This results from processes that follow basic soil thermodynamic principles but require microorganisms as catalysts. When soil is flooded, it becomes oxygen (O_2) depleted, changing the soil's redox potential. The latter is a simple measure of a soil's ability to oxidize or reduce substances chemically. Typically, values greater than +300 mV indicate an aerobic (oxygen-rich) environment, whereas values less than -100 mV indicate an anaerobic (oxygen-depleted) environment[1].

Oxygen diffusion through the soil is cut off when it is flooded, causing a shift from the microbial populations that decompose soil organic matter to those that can use electron acceptors other than O_2. First, nitrate is microbially reduced, followed by manganese, iron, and sulfate compounds. Although there is some overlap in this, as a final step in this sequence, CH_4 is produced by methanogenic bacteria[1].

In general, during prolonged absence of O_2, anaerobic processes such as CH_4 production prevail. However, methane formation may already occur at a soil redox potential that is not strictly anaerobic. Methanogenic bacteria also tolerate oxygen to some extent and thus survive occasional aeration (drying) of flooded soil environments[2]. Furthermore, these microbially driven processes occur simultaneously in heterogeneous soil microenvironments, including soil aggregates, a thin oxidized layer at the soil-floodwater interface, and the rhizosphere[1]. Various characteristics of the rice plant thus also interact with components of the growing environment (soil structure and chemistry, microbes, and saturation) to produce and release methane into the atmosphere.

HOW DOES THE METHANE FORMED REACH THE ATMOSPHERE?

In drained (aerated) soil, the porous spaces are gas-filled and contain molecular O_2, as well as carbon dioxide (CO_2) and nitrous oxide (N_2O) produced as by-products of respiration, nitrification and denitrification in the soil. These gases can easily diffuse from the soil to the atmosphere through gas-filled soil pores (Fig. 1). In flooded soils, however, the pores are filled with water, impeding molecular diffusion of gaseous compounds. CO_2 produced during respiration by roots or microorganism as well as CH_4 produced by methanogenic bacteria accumulate to high concentrations due to the slow diffusion. These gases are then primarily vented to the atmosphere through plant-mediated diffusion or, to a lesser extent, via ebullition (Fig. 1).

To grow in flooded soils, rice develops aerenchyma spaces in roots, internodes, and leaf blades. This forms a low-resistance pathway for the diffusion of O_2 from the atmosphere down to the flooded soil to maintain a thin, aerated layer around the roots, but in the same manner, CH_4 and CO_2 (also some N_2O) move in the opposite direction, from the rhizosphere to the atmosphere[3]. In a fully developed plant canopy, the aerenchyma serves as the conduit through which up to 90% of the CH_4 formed in the soil escapes to the air.

Rice has traditionally been grown mostly in flooded fields, as this enables good weed control, increases nutrient availability, conserves soil organic matter, and provides a growing environment for producing high and stable yields[4]. Depending on the cropping system, rice fields undergo cycles of flooding and drying that can occur one to several times a year. The lengths of periods under flooded (anaerobic) and non-flooded (aerobic) conditions may vary widely, and so do methane emission rates.

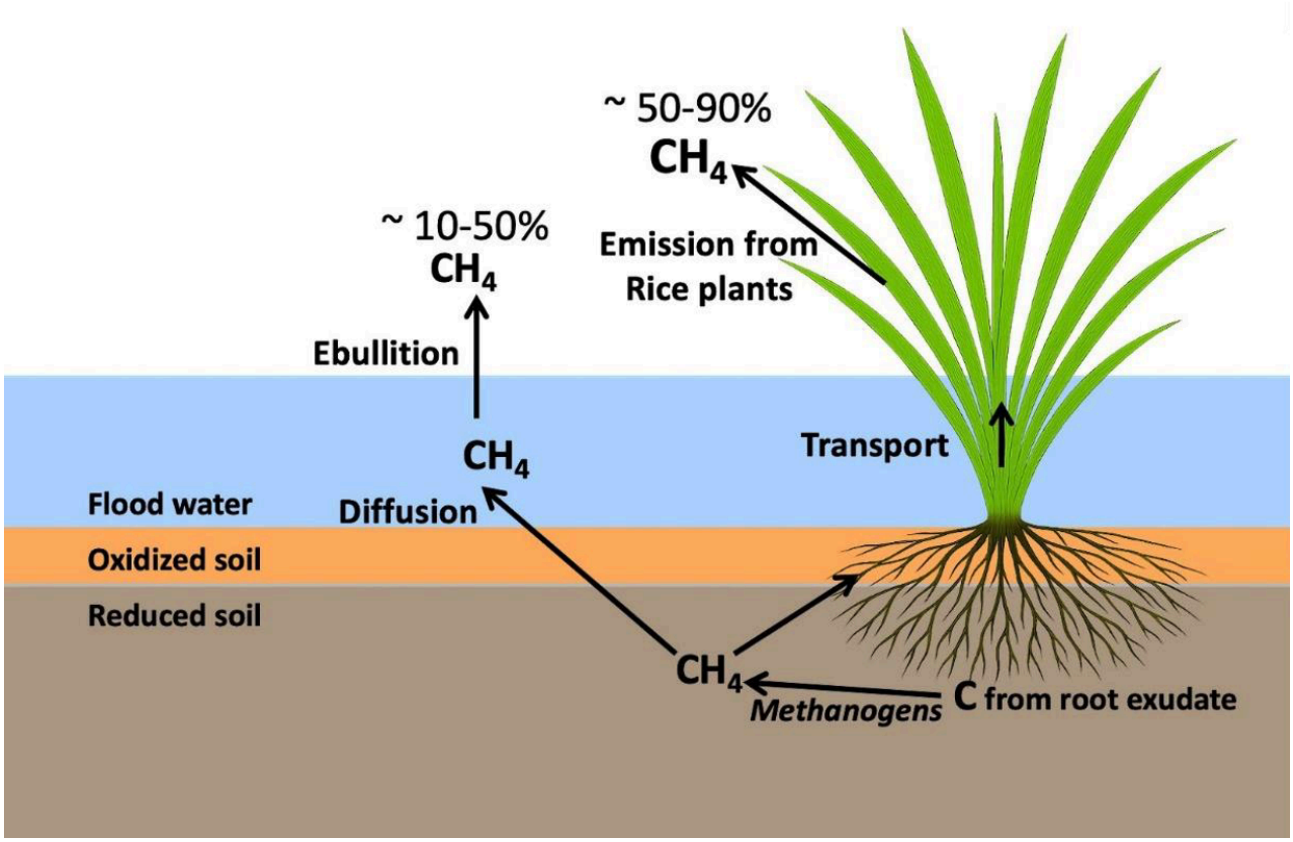

Figure 1: Methane production and emission from rice fields. Major methane emissions can occur through the plants and by ebullition. A small fraction is also lost through diffusion into the atmosphere (not shown). The percentages shown are the ranges from multiple studies under different field conditions.

REFERENCES

1 Kirk, G. J. D. The biogeochemistry of submerged soils (Wiley, New York, 2004).

2 Conrad, R. Methane production in soil environments-anaerobic biogeochemistry and microbial life between flooding and desiccation. *Microorganisms* **8,** 881; 10.3390/microorganisms8060881 (2020).

3 La Jiménez, J. d. C. & Pedersen, O. Mitigation of greenhouse gas emissions from rice via manipulation of key root traits. *Rice* **16,** 24; 10.1186/s12284-023-00638-z (2023).

4 Greenland, D. J. *The sustainability of rice farming* (CAB International, International Rice Research Institute, Oxon, Manila, 1997).