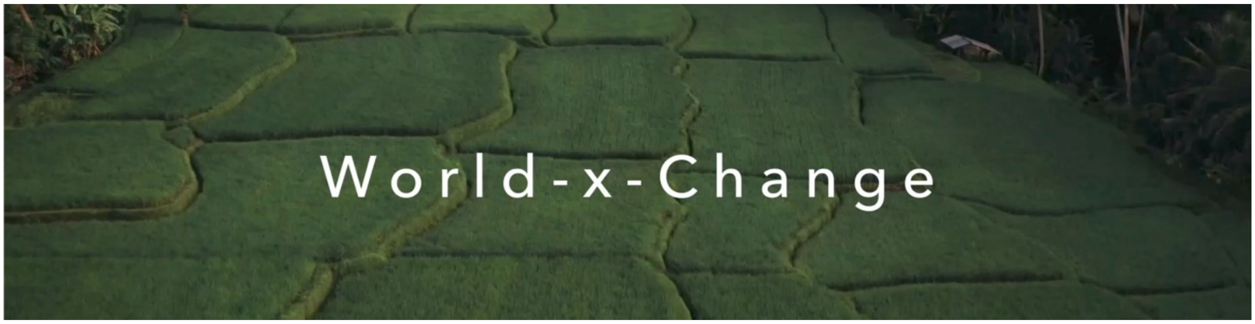

Carbon Emissions from Balinese Rice Paddies

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Our measurements of greenhouse gas emissions from Alternate Wetting and Drying[1] versus flooded rice paddies in the Balinese subaks use a new methodology made possible by recent advances in technology. Prior studies of such emissions relied on a point sample using a syringe draw from a closed chamber placed on the field. This sample was then sent to a laboratory to be analyzed using a gas chromatograph. Published measurements of emissions from flooded rice fields using such sampling vary widely, often by over an order of magnitude.[2] Recently, semi-portable gas spectrometers have become available that allow a field's emissions to be directly measured over an extended period of observation. Such measurements reveal the presence of critical discontinuities in the observed emissions that, if not accounted for, can have a large impact on the estimated emissions. For example, if a previously accumulated bubble of methane that is trapped in the paddy mud is released when the chamber is put in place, a single sample will not distinguish that event from the ongoing bioactivity of the rice plant.

Our emission measurements come from connecting field chambers directly to a laser spectrometer (Picarro, model g2508) that uses cavity ring-down spectroscopy to measure continuous gas flows at parts-per-billion accuracy over extended[3] periods of observation. As noted above, these measurements reveal discontinuities in the observed emissions that, if not accounted for, can adversely impact the results from the prior sampling methods. This may explain some of the large variance observed in these previous measurements.

A field-based spectrometer being used to measure emissions from adjacent Balinese rice paddies subject to different irrigation practices.

[1] There are many ways to implement Alternate Wetting and Drying. Rather than using a prespecified irrigation schedule, our version is driven by the presence of hairline cracks in the soil (as judged by each farmer).
[2] See https://www.ipcc-nggip.iges.or.jp/public/gl/guidelin/ch4ref5.pdf
[3] Around 60 minutes in the 2018 experiments, and 15-26 minutes in the 2020 experiments.

Paddy emissions are measured using a chamber attached to a gas spectrometer.

Our first emissions measurements using a field-based spectrometer began in 2018. We analyzed the emissions of two critical greenhouse gases, methane (CH_4) and nitrous oxide (N_2O), from two adjacent Balinese rice fields. The two fields received identical treatments except for irrigation: one used the centuries-old tradition of keeping the field continuously flooded (FLD) while the other (intermittent, INT) only added water when hairline cracks (as judged by each farmer) appeared in the exposed soil. In 2018, one site was sampled in each field during eleven dates in the middle of the growing season. In 2020 we repeated these experiments using three sampling sites in each field and extended the data collection to include nine dates between day 1 and day 52, with one final sample on day 94 (a few days before the harvest).

The net emissions rates of methane (measured in mg/m^2/h) from both the 2018 and 2020 experiments are shown in Figure 1. The raw concentrations of CH_4 measured in the chamber (mmol CH_4/l) were converted to a more meaningful area-based flux (mg CH_4/m^2/hr) using the dimensions of the chamber. The large emissions spike observed at sampling site 2 on day 8 in 2020 nearly doubled our estimate of g/m^2/season and, based on a detailed analysis of the continuous time series generated by the system, it was omitted from the calculations below. N_2O fluxes were negligible between the treatments and near zero. The above measurements were then integrated (using a composite trapezoidal rule and setting emissions at day 0 and 103 to zero) over the observations to calculate seasonal emissions. For further details, please see Lansing *et al.* (2023) and the associated supplemental material.[4]

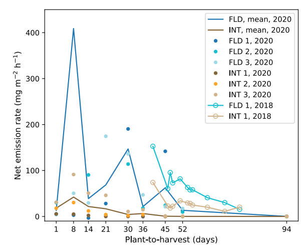

Figure 1: Methane emissions measured during our 2018 and 2020 field experiments.

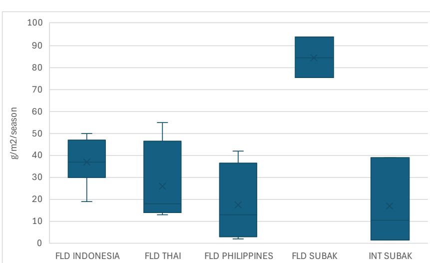

Figure 2: Estimated methane emissions for flooded (FLD) and intermittent (INT) irrigation. The first three locations (Indonesia, Japan, and Korea)[2] used syringe samples, the last two come from our 2020 Bali studies.

Using our emissions measurements, we can calculate the methane emissions avoided by using our version of Alternate Wetting and Drying (INT) versus flooding (FLD). Figure 2 compares the results of our 2020 studies with some published measures using the previous methodology. Using our 2020 data, FLD generated 76.8 g/m^2/season of CH_4 while INT generated 17.0 g/m^2/season of CH_4. Thus, irrigating using Alternate Wetting and Drying rather than flooding eliminates 59.8 g/m^2/season, **equivalent to a reduction of 33.5 tCO_2e/ha/yr.**[5]

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[4] Lansing JS, Kremer JN, Suryawan IBG, Sathiakumar S, Jacobs GS, Chung NN, Artha Wiguna IWA. Adaptive irrigation management by Balinese farmers reduces greenhouse gas emissions and increases rice yields. Philos Trans R Soc Lond B Biol Sci. 2023 Nov 6;378(1889):20220400. doi: 10.1098/rstb.2022.0400. Epub 2023 Sep 18. PMID: 37718599; PMCID: PMC10505851.

[5] Given 1000 g/kg, 1000 kg/tonne, 10000 m^2/ha, 2 seasons per year, and 28 CO_2e/CH_4 (in terms of Global Warming Potential), adopting Alternate Wetting and Drying saves 59.8 x 10000 x 2 x 28 / (1000 x 1000) or 59.8 x 0.56 = 33.5 TCE/ha/year.

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