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Soil and tree-stem methane and nitrous oxide fluxes from riparian areas with forest converted to smallholder oil palm and rubber plantations in Sumatra, Indonesia

Josephus Koks (1), Marife D. Corre (1), Oliver van Straaten (1), Aiyen Tjoa (2), Alexander Knohl (3), and Edzo Veldkamp (1)

(1) Georg-August University Göttingen, Department of Soil Science of Tropics and Subtropical Ecosystems, Göttingen, Germany, (2) Tadulako University, Fakultas Pertaninan, Palu, Indonesia, (3) Georg-August University Göttingen, Department of Bioclimatology, Göttingen, Germany

Increasing global demand for cash crops such as palm oil and rubber is causing large-scale forest-to-plantation conversion across Sumatra, Indonesia. While this land-use conversion is known to influence soil CH_4 and N_2O (*hereinafter referred to as greenhouse gas; GHG*) fluxes on well-drained soils, no one has reported on GHG fluxes in riparian areas. Our study quantified soil GHG fluxes from riparian areas, and measured the contributions of tree-stem GHG fluxes, another recognized pathway of soil- atmosphere GHG exchange in moist environments.

We selected the three dominant land use (LU) types in Jambi, Indonesia; lowland rain forest as a reference LU, and smallholder oil palm and rubber plantation as converted LU. We selected four plots as replicates per LU, on which we selected 4 to 6 sampling locations and 5 to 10 trees. Soil and stem GHG fluxes were measured using static chambers and stem chambers, respectively, on monthly basis, from March 2017 to March 2018, and statistically extrapolated to annual values.

Total annual CH_4 flux (in kg ha^{-1} yr^{-1}) was largest in the forest (2.62 $\pm$ 0.96 from soil, 0.33 $\pm$ 0.11 from stem), followed by oil palm plantation (0.68 $\pm$ 0.03 from soil, 0.52 $\pm$ 0.03 from stem), and rubber plantation (-0.55 $\pm$ 0.05 from soil, 0.02 $\pm$ 0.00 from stem). The rubber plantation showed a net negative soil CH_4 flux (uptake) throughout the year, whereas the forest and oil palm showed net soil CH_4 emission during the wet season. Total annual N_2O flux (in kg ha^{-1} yr^{-1}) was largest in the oil palm (3.28 $\pm$ 0.31 from soil, 0.09 $\pm$ 0.01 from stem), followed by forest (1.00 $\pm$ 0.02 from soil, *negligible* from stem), and rubber (0.65 $\pm$ 0.09 from soil, *negligible* from stem). The high net N_2O emissions in the oil palm are the result of additional N input via applied fertilizer, where we found an emission factor of 3.8 - 4.2 %. There was no significant change detected in neither soil, nor stem GHG fluxes (P = 0.13 - 0.97) after LU conversion.

Two important controlling factors were that 1) inundation events had an significant effect on soil and stem GHG fluxes; during inundation events (WFPS >= 100%), soil GHG fluxes decreased to almost zero, whereas stem GHG fluxes increased up to 350 times (forest), 70 times (palm oil), or even 1600 times (rubber), and that 2) a strong correlation between the soil (pore) CH_4 concentration at 40 cm depth and stem CH_4 flux in all LU types (ρ =0.27-0.93, P<0.05) suggested that stem-emitted CH_4 likely originated in the soil; in rubber, this correlation was also visible for N_2O (ρ = 0.32 - 0.50, P<0.05).

Soil and stem GHG fluxes from riparian areas were higher than those reported from comparable soils on well-drained areas. Our study highlights the importance of including the riparian areas, with their areal coverage in a certain landscape, to improve landscape-scale GHG flux estimates.